Walking Patterns in Older Adults: Modeling the Interplay of Frequency, Place, and Purpose

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ABSTRACT
Walking is an important physical activity with significant health benefits. Despite the presence of an extensive body of research dedicated to understanding various aspects of walking, there is a need for a more holistic and comprehensive understanding of walking behaviors. With many countries facing an increasingly aging population, this issue is of particular importance for older adults for whom walking can provide significant physical and mental health benefits. This paper studies three key walking behaviors: walking frequency, purpose, and place/location. The study utilizes data from the 2022 American Association of Retired Persons (AARP) walking survey and employs a multivariate ordered probit (MORP) approach to jointly model the three dimensions of walking. This method allows capturing exogenous variable effects and endogenous variable effects, while controlling for error correlations arising from the presence of unobserved traits that simultaneously affect multiple outcome variables. The survey also provides valuable data to examine other dimensions of walking behavior in older adults in a post-COVID environment, including duration, companionship, and perceived benefits and barriers. The findings indicate plenty of scope for enhancing purpose-driven walking through the provision of walk-friendly environments in and around residential neighborhoods. Significant socioeconomic disparities also hinder certain population segments from engaging in walking activities, particularly in their residential neighborhoods. The multidimensional dataset and findings obtained from this study offer a rich resource for future research, and for informing the design of urban planning and public health interventions, to promote walking and enhance quality of life among older adults.

Keywords: walking frequency, walking purpose, walking behaviors, transport and health, multivariate modeling

1. INTRODUCTION

Physical activity is universally recognized for its extensive health benefits, encompassing cardiovascular health, muscular strength, bone density, metabolic function, cognitive performance, mood regulation, anxiety reduction, and depression. The 2018 Physical Activity Guidelines Advisory Committee Scientific Report provides comprehensive documentation of the scientific evidence for these benefits (Physical Activity Guidelines Advisory Committee, 2018). Physically active older adults are less likely to experience falls, more likely to maintain functional ability and independence, and have a lower risk of dementia and improved mental health outcomes. Despite a wealth of knowledge about the benefits of physical activity, it remains a significant public health challenge. While the U.S. Department of Health and Human Services (USHHS) recommends that adults engage in at least 150 weekly minutes of moderate-intensity aerobic physical activity to accrue health benefits, a large fraction of adults, particularly older adults, do not meet this recommendation. Specifically, only 13.9% of individuals aged 65 and older meet this standard, compared to 49.7% of all adults in the 18-64 year age group (National Center for Health Statistics, 2019).

As populations age globally, understanding the patterns and determinants of physical activity in older adults becomes critical for promoting public health and enhancing quality of life. Among the various forms of physical activity, walking stands out as a particularly promising option, especially for older adults. It is one of the most commonly performed aerobic activities and is associated with a wide range of health benefits. Walking is accessible, requires no special equipment, and can be easily incorporated into daily routines. Furthermore, it is considered one of the safest forms of physical activity, relative to more strenuous physical activities such as running or contact sports, making it an ideal choice for older adults with concerns about injury or who are just beginning to increase their activity levels.

However, walking is not a monolithic activity; it occurs in various places and serves different purposes, with these characteristics often interacting in complex ways. For instance, walking the dog (purpose) in the neighborhood (place) differs greatly from walking briskly at a gym (place) for structured exercise (purpose). Individuals can also combine purposes, for example, by walking in a park (place) for exercise (purpose) and social interaction (purpose), in their neighborhood (place) for both health benefits (purpose) and running errands (purpose), or in a shopping mall (place) for physical activity (purpose) in a climate-controlled environment while also accomplishing daily tasks (purpose). The nature of the trip's purpose, be it for health, transportation, social engagement, or daily tasks, may dictate the place chosen for walking due to physical and functional constraints. Conversely, the places available for walking can shape the purposes for which (older) adults walk.

Additionally, walking places and purposes can influence or be influenced by walking frequency. The purpose of walking can affect both the place and frequency; for example, an older adult who walks primarily for exercise might choose a local park and maintain a frequent walking schedule. Similarly, walking frequency can influence choices of place and purpose; a highly active older adult might seek out varied locations and walk-friendly built environments to maintain high levels of walking, combining exercise walks in a park with social walks in a shopping center. In addition to such direct effects of one walking dimension on another, observed and unobserved aspects related to the quality and safety of the walking environment can shape all the three aspects of frequency, purpose, and place of walking, engendering a relationship among these three dimensions of walking choice. For example, a well-maintained hiking trail nearby might encourage more frequent walks for leisure at the trail. As another example, the environmental factors of an outdoor roadway location, including high traffic volumes/vehicle speeds on roadways in the neighborhood, heterogeneous traffic mix on roadways (such as high presence of trucks or buses), and poor infrastructure features (such as poor lighting and lack of safe sidewalks on roadways) can all increase the risk of traffic crashes (see Macioszek et al., 2023), thus reducing walking frequency for any purpose as well as influencing the place of walking (see, for example, Ferrer et al., 2015 and Campos Ferreira et al. 2023). In fact, as our own empirical findings later indicate, and also as evidenced by earlier research, those who are more worried about the risk of traffic crashes (for instance, those who identify as being a woman) appear to be more likely to walk in indoor environments (such as gyms and malls) relative to those who appear less worried about the risk of traffic crashes (for instance, those who identify as being male).

In contrast to the strong interrelationship among different dimensions of walking behavior, as just discussed, current research on walking often focuses on overall physical activity levels, such as frequency and duration (see Buehler and Pucher, 2024, and Hwang et al., 2024), without adequately considering the rich array of attributes that characterize/describe walking behaviors. This study aims to present a multidimensional exploration of the varied aspects of walking, including frequency, purpose, and place, with a view to develop a comprehensive understanding of walking patterns among older adults. Such an understanding is essential for informing public health initiatives, urban planning, and policymaking aimed at encouraging walking among older adults, ultimately contributing to healthier and more active aging in the population.

In order to accomplish this multidimensional analysis of walking behaviors, this study presents a multivariate joint econometric model system of walking frequency, purpose, and place that is capable of capturing the strong interrelationships between these three attributes of walking. The multivariate modeling approach enables the estimation of the effects of socioeconomic and demographic factors on all three aspects of walking behavior, while also accounting for the relationships among the three dimensions of interest. The modeling effort utilizes data from the "American Association of Retired Persons (AARP) Walking Survey: Attitudes and Habits of Adults Aged 50 and Older" conducted in July 2022.

The remainder of this paper is organized as follows. The next section presents a brief literature review on walking behaviors. The third section presents a description of the survey data, while the fourth section offers a brief overview of the modeling methodology and formulation. Model estimation results are presented in the fifth section. The sixth section presents an analysis of average treatment effects and their implications, while the seventh and final section offers concluding thoughts.

2. LITERATURE REVIEW

The determinants of walking frequency among older adults have been the subject of numerous studies in recent years. A comprehensive review by Hwang et al. (2024) synthesized findings from a wide range of research studies focused on this topic. Their analysis also quantified the impact of various sociodemographic factors on the walking habits of older adults. Their findings revealed that older unemployed adults, individuals from low-income or minority households, women, and older adults living with children tended to walk less frequently.

Trip purpose is an aspect that has not received extensive attention in the context of walking behaviors. As Bozovic et al. (2020) state, “Trip purposes were globally poorly accounted for.” Also, most studies that include trip purpose considerations predominantly study the frequency, distances, and durations of walking trips for different purposes rather than exploring why people walk in the first place. Yang and Diez-Roux (2012) found that walking distances and durations for recreation were substantially longer than those for other purposes. Their study revealed that the shortest distances and durations were observed for trips related to meals, while work trips were shorter in distance than recreation trips but longer than study and social event trips. In another study, Pae and Akar (2020) found that “home-based other” and “home-based recreational” walking trips had the longest durations compared to other trip types. Further, studies by Watson et al. (2020) and Macioszek et al. (2022) highlighted a shift in walking purposes with age as social and recreational walking trips increase and work-related walking trips decrease. Hatamzadeh et al. (2014) noted that seniors might, however, be more willing to walk for work trips due to potential limitations in driving. Women were generally more likely to walk for discretionary, recreational, and shopping trips, while men showed higher rates of walking for work-related trips (see Agrawal and Schimek, 2007, Hatamzadeh et al., 2014, Watson et al., 2020, and Macioszek et al., 2022). However, some studies found the opposite trend (see Hatamzadeh et al., 2014) or no significant gender differences for mandatory trips (see Macioszek et al., 2022). People with lower household incomes walked longer distances for work but shorter distances for recreation (Yang and Diez-Roux, 2012). Also, Hearst et al. (2013) found that residents in disadvantaged areas walked more for daily transportation needs. Additionally, as income and education levels increase, walking for mandatory trips generally decreases, while findings on recreational walking were mixed (see, for example, Agrawal and Schimek, 2007, and Watson et al., 2020).

Sugiyama et al. (2018) and Perchoux et al. (2019) highlighted the significance of “aging in place,” which depends on the capacity of older adults to go outdoors and complete everyday tasks. They observed that as people aged, the distance they were willing to travel for activities generally decreased, emphasizing the critical role of residential neighborhood amenities. Residential built environment plays a crucial role in facilitating or hindering walking among older adults. This aligns with findings from Cerin et al. (2017), who stressed the significance of the residential environment for short-distance, utilitarian walking trips among older adults. Several systematic reviews have synthesized the evidence linking residential built environment attributes with physical activity and walking behavior (see Wang et al., 2016, Cerin et al., 2017, and Bonaccorsi et al., 2020). These studies have reported evidence of strong positive associations between walking, residential density/urbanization, walkability, street connectivity, overall access to destinations/services, land use mix, pedestrian-friendly features, and access to diverse destinations. Bozovic et al. (2020) further noted that proximity to destinations was particularly important for older adults, especially those who do not drive or anticipate not being able to drive in the future. Additionally, Liu et al. (2022) reported that perceived comfort was significantly associated with the intention to walk among older adults. Other environmental factors, such as littering/vandalism/decay, traffic and crime-related safety, limited resting places, tripping hazards, precipitation, and temperature extremes, were also negatively related to total walking (see King et al., 2016).

More recently, Motomura et al. (2022) conducted a systematic review of 18 observational studies, finding positive associations between public open space (POS) attributes and leisure-time physical activity. They highlighted studies examining the effects of proximity to or availability of POS attributes on walking among older adults. For instance, Yeh et al. (2018) and Yuen et al. (2019) found that parks closer to home contributed more to park-based physical activity than those located further away. This finding is particularly relevant for older adults. Some studies also found that a greater number of parks in participant’s home neighborhoods contributed positively to leisure-time physical activity among older adults (see, for example, Cerin et al., 2013, and Yeh et al., 2018), with those aged 75 and over being particularly sensitive to the presence of nearby parks (Bozovic et al., 2020).

While much research focuses on outdoor environments, indoor walking locations are also important spaces for older adults. King et al. (2016) explored the use of malls and other public spaces for walking among older adults. They found that mall walking has long been popular with this age group since it offers several advantages, including safety from traffic and crime, maintained and even walking surfaces with limited tripping hazards, benches along walking routes, clean public restrooms, and protection from climatic barriers such as heat, cold, wind, darkness, and precipitation. King et al. also observed some demographic differences between mall and non-mall pedestrians, wherein malls attracted more older adults, ethnic minorities, and males, while non-mall venues attracted a higher proportion of adolescents and middle-aged adults. They suggested that factors such as proximity to residential areas, consistent walking hours, and absence of entry fees might influence these patterns of location choice. Kerr et al. (2012) compared outdoor physical activity to indoor activity among older adults in two U.S. regions. They found that older adults who were physically active outdoors accumulated significantly more physical activity.

Overall, while earlier research studies have provided valuable insights on walking behaviors among older adults, they have not adequately considered the inter-relatedness among the dimensions of frequency, purpose, and place of walking; that is, earlier research has typically examined the dimensions of walking behavior in a fragmented and isolated fashion. Besides, earlier studies have typically considered only a single aggregate purpose (either walking for leisure or walking for utilitarian purposes), rather than considering a diverse collection of different disaggregated walking purposes. Also, on the "walking place" dimension, earlier research has either ignored this dimension entirely, or emphasized outdoor walking around residential areas or parks, seldom considering indoor walking as another place for older adults to accrue the health benefits of walking. Within the relatively disjointed examination of walking behavior dimensions in this earlier body of research, our study aims to provide a comprehensive multidimensional picture of walking behaviors and patterns among older adults in a way that provides important insights to promote walking. In particular, there are several salient aspects of our research. *First*, our study provides a novel approach for jointly modeling walking frequency, purpose, and place in a comprehensive, integrated multivariate ordered-response probit framework to estimate the effects of sociodemographic factors on all three walking dimensions of interest. This approach allows the ability to explore alternative directions of causality among the walking behavior dimensions of interest and control for unobserved factors that lead to associations among the aspects of walking behavior, thus offering more accurate estimates of the causal effects between walking frequency, purpose, and place. *Second*, this study incorporates a unique set of purpose and place choices. For the purpose dimension, recreation/leisure/strolling, exercise, transportation, pet walking, and workplace walking are considered. For place, a diverse range of alternatives is considered, including residential areas, parks, malls, gyms, waterside locations, and other outdoor spaces. *Third*, a significant contribution of this study lies in its specific focus on older adults. Given their unique mobility challenges and the health benefits of walking, it is important to develop models specific to this population segment, given its growing share of the U.S. population (Caplan, 2023). The analysis in this paper also provides a more stable and timely characterization of post-pandemic walking behaviors as it uses revealed preference data on walking habits of older adults from July 2022. *Fourth*, while many walking studies focus on the effect of the built environment on walking behavior, this research effort emphasizes the interactions among sociodemographic factors. This approach helps clarify how variables such as age, income, gender, and education simultaneously affect different aspects of walking behavior among older adults. *Fifth*, this study extends the analysis beyond model estimation to predict the magnitude of explanatory variable effects on various walking outcomes. This predictive analysis is particularly valuable for policymaking and designing urban planning strategies and public health interventions that promote walking among older adults.

3. DATA DESCRIPTION

This section summarizes the survey and data set used in this study. First, the survey and sample characteristics are described. Then, a more detailed descriptive analysis of endogenous variables is provided.

3.1. Survey Overview and Sample Characteristics

This study utilizes data from the "AARP Walking Survey: Attitudes and Habits of Adults Aged 50 and Older" (AARP, 2022). The survey gathered data about walking behaviors from 1,691 adults aged 50 and older in the U.S. via the National Opinion Research Center (NORC) Foresight 50+ panel. It was conducted between July 21 and July 26, 2022. After extensive data cleaning and removing obviously erroneous entries, 1,667 observations were retained in the final analysis sample.

The study incorporates a range of sociodemographic factors to understand their influence on walking behavior in older adults. These factors include individual characteristics such as age, gender, education level, employment status, and race, as well as household characteristics such as income, marital status, and household composition. Additionally, the influence of weather and social environment is captured by considering the respondent's region of residence.

To ensure the generalizability of study findings to the broader population aged 50 and over, sample demographics were compared with benchmark data from NORC's report, derived from the U.S. Census Current Population Survey (CPS) and the American Community Survey (AARP and NORC, 2022). This comparison is depicted in Table 1. The survey sample shows some notable differences stemming from an intentional oversampling of non-white individuals, with 44.8% of the sample being white and non-Hispanic, compared to 70.7% in the census data for this age group. Consequently, there is a higher representation of non-Hispanic Black, non-Hispanic Asian, and Hispanic individuals. Additionally, the sample has a higher proportion of seniors (65 years or older), men, those with middle and higher education levels, employed individuals, and never-married individuals. At the household level, middle-income households and those living with children (defined as individuals under 18 years old) are over-represented. Despite these differences, the sample depicts variations in sample attributes that are desirable for a modeling effort of the nature undertaken in this study. The unweighted sample is used for model estimation purposes. This approach aligns with the focus on understanding individual-level relationships between sociodemographic factors and aspects of walking behavior. In this context, the key consideration is whether the sampling strategy itself influences the modeled outcomes. Since the sampling approach can be considered exogenous to the walking behaviors being analyzed, the unweighted modeling approach is both efficient and statistically robust (see Wooldridge, 1995, and Solon et al., 2015).

Table 1 also presents the distributions of the three endogenous outcome variables of interest, which may be summarized as follows:

1. *Walking Frequency:* Measured as the number of days per week participants reported walking for at least ten consecutive minutes, regardless of reason. The survey question is

as follows: In a typical week, how many days do you walk for at least ten consecutive minutes at a time, for any reason? Response options include: Never, 1-2, 3-4, 5-6, or 7 days per week.

2. *Walking Purpose:* Defined as the reasons for which participants engage in walking for ten consecutive minutes or longer in a typical week. Participants could select multiple reasons. The survey question is as follows: In a typical week, do you ever walk for 10 minutes or longer at a time for any of the following reasons? (Select all that apply). The options, along with their labels, are:
    - At work (if you are employed) – Work
    - Walking a pet – Walk pet
    - Brisk walking for exercise – Exercise
    - To get to and from the places I need to go (e.g., walking to and from: a friend's house, a store, work, the library, etc.) – Transport
    - Hiking – Exercise
    - Leisurely walking/strolling – Recreation
    - Recreation – Recreation

    As may be observed, a few alternatives/options were strategically combined because of (a) few responses in the more disaggregated categories, and (b) similarity of coefficient estimates for these options in initial exploratory model estimation exercises. Specifically, the following categories were merged: "Leisurely walking/strolling" with "Recreation," and "Brisk walking for exercise" with "Hiking" into a single "Exercise" category.

3. *Walking Place:* Identified as the locations where participants typically walk for at least ten minutes at a time. Participants could select multiple locations. The survey question is as follows: When you walk for at least 10 minutes at a time, where do you typically walk? (Select all that apply)
    - A park – Park
    - My neighborhood – Residential neighborhood
    - Another neighborhood – Residential neighborhood
    - Fitness center or gym – Gym/indoor
    - Mall or shopping center – Mall
    - The beach – Waterside/outdoor
    - Along a river or canal – Waterside/outdoor
    - Another indoor space – Gym/indoor
    - Another outdoor space – Waterside/outdoor

    Again, some of the options were combined (as indicated by the labels above) for the same reasons as mentioned earlier for walking purpose: "My neighborhood" with "Another neighborhood" into a single "Residential neighborhood" category; "Fitness center or gym," "At work…," and "Another indoor space" into a single "Gym/indoor" category; and "The beach," "Along a river or canal," and "Another outdoor space" into a single "Waterside/outdoor" category.

Respondents who reported never walking more than ten consecutive minutes per day were not asked about their walking purpose and place. In this particular data set, we found that 18.9% of the respondents reported never walking for at least ten consecutive minutes in a typical week. The most frequent walking pattern was 3-4 days per week (27.9%). Among those who walked for at least ten minutes one or more times a week, further analysis of purposes and places of walking may be conducted. Distributions for the aggregated purpose and location categories are shown in Table 1. Recreational walking is the most common purpose (55.7%), followed by walking for exercise (44.0%). Regarding the place of walking, residential neighborhood is the most frequent choice (69.2%), followed by waterside/outdoor areas (31.3%).

TABLE 1 Socioeconomic and Demographic Characteristics of the Sample (N = 1,667)

Variable	Attribute	% in Sample	% in Benchmark (2021)
Age	50-64 years	43.4	52.1
	65 years or older	56.6	47.9
Gender	Female	47.9	52.8
	Male	52.1	47.2
Education	High school or less	23.2	40.8
	Some college or Bachelor	62.2	44.9
	Some graduate degree or higher	14.6	14.3
Employment status	Employed	48.1	45.3
	Unemployed	51.9	54.7
Race and ethnicity	Asian, non-Hispanic	9.7	5.4
	Black, non-Hispanic	21.6	10.7
	Hispanic	22.9	11.7
	Others	1.0	1.5
	White, non-Hispanic	44.8	70.7
Household income	Less than $50,000	19.1	35.7
	$50,000 - $99,999	46.4	27.9
	More than $100,000	34.5	36.4
Marital status	Married	54.7	58.1
	Divorced/Separated/Widowed	31.0	34.2
	Never married	14.3	7.7
Presence of household child	No	81.9	86.4
	At least a child (<18 years)	18.1	13.6
Outcome Variables			
Weekly walking frequency (N = 1,667)	Never	18.9	--
	1-2 days	17.1	--
	3-4 days	27.9	--
	5-6 days	21.2	--
	7 days	14.9	--
Walking purpose* (N = 1,352)	Recreation	55.7	--
	Exercise	44.0	--
	Transport	36.8	--
	Walk pet	25.6	--
	Work	32.8	--
Walking place* (N = 1,352)	Residential neighborhood	69.2	--
	Park	28.8	--
	Mall	23.2	--
	Gym/indoor	23.1	--
	Waterside/outdoor	31.3	--

*percentages do not add up to 100% as respondents could select multiple options

4. MODELING FRAMEWORK

This section presents the model structure and framework adopted in this study. First, a qualitative depiction of the modeling methodology is presented, followed by the details of the formulation and estimation methodology.

4.1. Model Structure

Figure 1 presents a simplified representation of the adopted model structure. The exogenous variables on the left side of the figure represent individual and household sociodemographic characteristics. The right side of the figure, within the box labeled "Outcome Variables," shows the three walking dimensions of interest: frequency, purpose, and place. For ease of presentation, Figure 1 does not display the correlations and endogenous effects between the outcome variables. The outcome variables constitute a series of discrete variables. The walking frequency is an ordinal variable, while all options under walking purpose and walking place are represented as a series of binary variables indicative of whether or not a respondent selected a particular purpose or location. In all, there are eleven outcome variables, ten of which are discrete binary variables (five each for purpose and location), and one is an ordinal frequency variable.

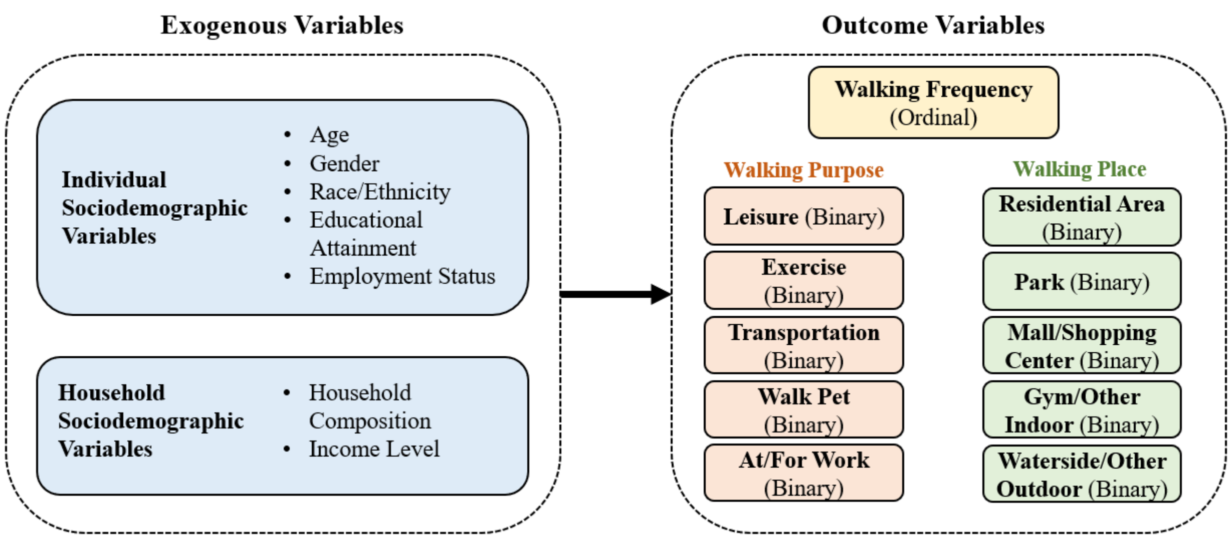

Figure 1 Model Structure and Framework

4.2. Model Estimation Methodology

The modeling framework used for analyzing walking behavior takes the form of a multivariate ordered-response probit (MORP) model system. Methodologically speaking, for any given individual, if the individual walks for at least ten consecutive minutes one or more times a week, the joint probability of interest corresponds to the frequency of walking, the choice of walking purposes (yes/no, based on observation on each of the five walking purposes), and the choice of walking places (yes/no, based on observation on each of the five walking places). Conversely, if the individual never walks for at least ten consecutive minutes, then that individual is observed only for the walking frequency dimension. As such, the model structure is essentially that of a multivariate ordered probit system with eleven outcome dimensions for those who walk for at least ten consecutive minutes on any day of the week, and a single univariate ordered probit system for walking frequency (with the observed outcome being "never") for those who never walk at least ten consecutive minutes on any day of the week. Here, we provide the methodology for only the former group of respondents, with the univariate ordered probit system being simply a marginalized version of the methodology presented here.

In the following presentation, the notation q for individuals is suppressed, and the likelihood contribution for each individual q is derived. Let i be the index for walking frequency, the five walking purposes, and the five walking places ($i = 1, 2, \ldots, I$; I=11 in the current empirical analysis). Also, let the ordered-response level for outcome i be k_i {1, 2, …, K_i}, where K_i is the highest level corresponding to variable i. Suppose in this formulation i=1 refers to the walking frequency outcome, which implies that K_1=5. For i >1, K_i=2 since it corresponds to a yes/no choice for each walking purpose/place. In conventional ordered response formulation,

$$y_i^* = \boldsymbol{\beta}_i'\mathbf{x} + \varepsilon_i, y_i = k_i \text{ if } \theta_i^{k_i-1} < y_i^* < \theta_i^{k_i}, \quad (1)$$

where $\mathbf{x}$ is an ($L\times1$) vector of exogenous variables (including a constant) as well as possibly the observed values of other endogenous variables, and $\boldsymbol{\beta}_i$ is a corresponding ($L\times1$) vector of coefficients to be estimated (some of those coefficients can, and in general, will be zero). ε_i is assumed to be a normal error term (the scale of ε_i is not identified and so is arbitrarily set to one). Also, $\theta_i^{k_i}$ is the upper bound threshold for level k_i, satisfying $\theta_i^0 < \theta_i^1 < \theta_i^2 ... < \theta_i^{K_i-1} < \theta_i^{K_i}$; $\theta_i^0 = -\infty$, $\theta_i^1 = 0$, $\theta_i^{K_i} = +\infty$ for each outcome i. The ε_i terms are assumed normally distributed with zero mean and a scale of one for identification reasons. Then, $\boldsymbol{\varepsilon} = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_I)'$ follows a multivariate normal distribution with an ($I\times1$) mean vector of zeros $\mathbf{0}_I$ and an ($I\times I$) correlation matrix $\boldsymbol{\Sigma}$.

Collapsing this formulation into matrix notation, let $\boldsymbol{\beta} = (\boldsymbol{\beta}_1, \boldsymbol{\beta}_2, ..., \boldsymbol{\beta}_L)'$ [($I\times L$) matrix]. Also, define the vector of thresholds for each outcome variable $\boldsymbol{\theta}_i = (\theta_i^2, \theta_i^3, ..., \theta_i^{K_i-1})'$ and vertically stack all $\boldsymbol{\theta}_i$ vectors into a single vector $\boldsymbol{\theta}$. Let the individual under consideration select level m_i. Stack the lower thresholds $\theta_i^{m_i-1}$ corresponding to the observed values of the individual into an ($I\times1$) vector $\boldsymbol{\theta}_{low}$, and the upper thresholds $\theta_i^{m_i}$ into $\boldsymbol{\theta}_{high}$. Also, stack the y_i^* latent variables into an ($I\times1$) vector $\mathbf{y}^*$. Then, in matrix form, for the individual under consideration, we have:

$$\mathbf{y}^* = \boldsymbol{\beta}'\mathbf{x} + \boldsymbol{\varepsilon}, \; \boldsymbol{\theta}_{low} < \mathbf{y}^* < \boldsymbol{\theta}_{high}, \text{ with } \mathbf{y}^* \sim MVN_I(\boldsymbol{\beta}'\mathbf{x}, \boldsymbol{\Sigma}). \quad (2)$$

Lastly, define a vector $\boldsymbol{\delta}$ that holds the collection of parameters to be estimated $\boldsymbol{\delta} = (\boldsymbol{\beta}', \boldsymbol{\theta}')'$. Then, the likelihood function for the individual under consideration may be written as:

$$\begin{aligned} L(\boldsymbol{\delta}) &= \Pr\left[\boldsymbol{\theta}_{low} < \mathbf{y}^* < \boldsymbol{\theta}_{high}\right], \\ &= \int_{D_r} f_I(\boldsymbol{r} \mid \boldsymbol{\beta}'\mathbf{x}, \boldsymbol{\Sigma}) d\boldsymbol{r}, \end{aligned} \quad (3)$$

where the integration domain $D_r = \{\boldsymbol{r} : \boldsymbol{\theta}_{low} < \boldsymbol{r} < \boldsymbol{\theta}_{high}\}$ is simply the multivariate region of the $\mathbf{y}^*$ vector determined by the upper and lower thresholds. $f_I(\boldsymbol{r} \mid \boldsymbol{\beta}'\mathbf{x}, \boldsymbol{\Sigma})$ is the multivariate normal (MVN) density function of dimension I with a mean of $\boldsymbol{\beta}'\mathbf{x}$ and a correlation matrix $\boldsymbol{\Sigma}$. Bhat's (2018) matrix-based efficient and accurate analytic approximation method for evaluating the multivariate normal cumulative distribution (MVNCD) function is employed to evaluate this integral. The log-likelihood function for a sample of Q decision-makers is obtained as the sum of the individual-level log-likelihood functions.

All model estimations and post-analyses presented in this paper were undertaken using specialized code written in the GAUSS matrix programming language (Aptech, 2024).

5. MODEL ESTIMATION RESULTS

This section presents the model estimation results for the eleven outcomes of interest in the study (walking frequency, five walking purposes, and five walking places). The selection of explanatory variables for our model was based on a systematic approach that considered both theoretical relevance and statistical robustness. We began by considering all sociodemographic variables available in the dataset as exogenous variables. This comprehensive initial approach ensured that we considered the full range of potentially influential variables. Then, we conducted preliminary univariate analyses to identify variables showing statistically significant associations with each of the eleven outcome measures of walking frequency, purpose, and place individually. In doing so, we explored various functional forms and combinations for the explanatory variables, testing different specifications for continuous variables and groupings for categorical variables. Once the exogenous variables and their functional forms were identified from the univariate analysis for each of the eleven outcomes, we retained those variables and functional forms in the multivariate ordered-response probit analysis. The final model specification was determined based on the statistical significance of individual variables, overall model fit, and parsimony considerations. In the final specification, presented in Table 2, some variables that were not significant at the 0.05 level were retained for behavioral intuitiveness. Table 2 presents estimation results where the coefficients are reported together with their level of statistical significance. Note that the values reported in the "Thresholds/Constants" panel of Table 2 do not have any substantive interpretations. These thresholds serve as a mapping mechanism to translate the underlying propensity to the observed ordinal category.

5.1. Exogenous Effects

Model estimation results are largely intuitive and consistent with findings reported earlier in the literature. Compared to individuals aged 50-64, those 65 and over are more likely to engage in walking for exercise, as well as mall walking. This is consistent with expectations as those who are older may find walking a low-impact method of exercise and find the mall location to be a safe and secure walking environment. These findings align with those reported earlier, where mall walkers tended to be over 65 years old (see King et al., 2016). On the other hand, those 65 or above are less likely to walk for work, presumably because they are retired and beginning to experience mobility limitations.

Women in the 50+ age group have a lower propensity to walk frequently compared to men, consistent with previous research (Hwang et al., 2024). They also exhibit a lower likelihood of engaging in recreational walking (consistent with Zhao et al., 2024), walking for work, and walking in parks, waterside areas, or other outdoor locations. In contrast, women are more likely to walk in malls, gyms, and other indoor locations largely because they are safer, protected from weather, and provide amenities, as also observed by King et al. (2016), and Li et al. (2017). Previous research by Zhao et al. (2024) further supports this finding by demonstrating women's tendency to report higher traffic safety concerns than men.

Race and ethnicity are strongly associated with walking behaviors. Individuals identifying as non-white have a higher propensity to walk frequently, especially for exercise purposes. In contrast, they are less likely to engage in recreational walking or walking pets compared to white individuals. Regarding walking locations, non-white individuals tend to walk more in parks, malls (consistent with King et al., 2016), gyms, and indoor locations. They are less likely to walk in residential neighborhoods, waterside, or other outdoor places. The lower likelihood of residential walking among non-white individuals may be attributed to systemic inequalities, with neighborhoods predominantly inhabited by racial minorities potentially being less walkable or perceived as less safe (Haddad et al., 2023). Educational attainment also plays a significant role in shaping walking behaviors (see Buehler and Pucher, 2024). Individuals with a high school diploma or lower level of formal educational attainment exhibit a lower likelihood of engaging in recreational walking and walking for exercise. At the same time, they are more likely to walk for work purposes, although this may be attributed to lower car ownership levels and to the occupational profile of individuals in this education group. Previous studies by Watson et al. (2020) and Macioszek et al. (2022) support this finding, indicating a trend for less leisure walking and more mandatory walking among individuals reporting lower educational levels. Conversely, those with graduate degrees and above tended to utilize walking more as a means of transportation (i.e., getting to and from places). Studies in social-psychological literature suggest that higher educational attainment is, in fact, associated with increased environmental awareness, leading individuals to choose walking over motorized transportation to reduce their environmental impact (see Liu et al., 2020). Lastly, the results show a negative relationship between educational attainment and walking pets.

Employed individuals are less likely to walk for exercise or transportation, perhaps due to time constraints or because they fulfill their walking needs through walking to or at work. Interestingly, employed individuals are less likely to walk in residential areas than their unemployed counterparts, partly because employed individuals are able to walk in locations or avail of fitness facilities close to their work location. As expected, the effect of income on walking behavior shares many similarities with that of educational attainment. Individuals from low-income households tend to walk more frequently, perhaps due to vehicle deficiency or to save money. This is also supported by the finding of a higher likelihood of utilizing walking for transport purposes, which aligns with results reported earlier (Hearst et al., 2013). Lower income is also associated with more walking at/for work, likely because low-income jobs are more often physically demanding. However, high income is associated with more recreational walking, exercise, and walking pets, consistent with results reported by Macioszek et al. (2022). Regarding walking locations, lower-income individuals are less likely to walk at gyms or other indoor places, presumably due to monetary constraints. Conversely, those from households with annual incomes over $100,000 are less likely to walk in malls and more likely to walk in their residential neighborhoods (which are likely to be nice and safe).

Housing type primarily affects pet-walking behavior, with apartment dwellers less likely to walk pets. This is likely due to apartment restrictions and space limitations suppressing pet ownership rates. Individuals living in households with children have a lower propensity for frequent walks, possibly due to time constraints associated with childcare responsibilities. However, the presence of children affects the choice of walking locations. These households show a higher propensity to walk in residential neighborhoods and parks. Residential areas are convenient, safe, and easy to access within household time constraints, while parks provide safe, child-friendly features such as playgrounds that appeal to such households. Finally, Table 2 shows that there are some regional geographical differences in walking behaviors. These variables are included primarily as controls to estimate other individual-level effects more accurately. More detailed built environment and contextual variables are needed to fully assess the influence of such attributes on walking behaviors, while also recognizing that there may be self-selection effects at play when determining built environment effects.

Overall, the exogenous variable effects from our study are generally consistent with earlier studies that examine each walking dimension separately, as identified in the discussion of individual variables above. As a quick summary, the oldest group of adults walk more in malls and for exercise, and less for work; women tend to walk less frequently across all purposes and places (and especially for work/recreational purposes and in outdoor locations); individuals identifying as non-white or reporting low household income generally walk more frequently than those who identify as being white or reporting high household income, though individuals identifying as white and reporting high income walk more for recreational reasons; employed individuals are less likely to walk in and around their neighborhoods relative to unemployed individuals, while those with children in the household walk more around their neighborhoods than those without children.

Unlike earlier studies, however, the effects above constitute direct exogenous variable effects after accounting for the indirect effects of exogenous variables through causal endogenous effects of other walking-related variables (which we refer to as endogenous effects). Also, the exogenous variable effects in our paper represent the "cleansed" influence of exogenous variables after accounting for common unobserved individual-level factors that can influence the many walking dimensions (which we refer to as correlation effects). These endogenous and correlation effects are discussed below; our control of these endogenous and correlation effects provides a more accurate net overall effect of exogenous variables on each walking dimension relative to earlier studies (please also see Section 6).

5.2. Endogenous and Correlation Effects

Model estimation results show that there are a number of significant endogenous variable effects among the dimensions of interest. The model framework accommodates jointness among the walking frequency, purpose, and place dimensions through the correlation matrix presented in Table 2. By controlling for unobserved factors that lead to associations among the different outcomes and then estimating endogenous effects between these outcomes, the model specification captures the uncorrupted "true" causal effects among the walking dimensions. In a joint limited dependent (LD) outcomes model (which only includes non-continuous outcome variables), only the recursive and triangular effects of one endogenous observed variable on the underlying propensity of another endogenous variable can be estimated due to logical consistency considerations (see Maddala, 1976 and Bhat, 2015 for details). Intuitively, recursiveness and non-cyclicality in the relationship among the LD outcomes ensures that you cannot have an underlying latent continuous variable determine an observed outcome as well as also have the logical inconsistency of that observed outcome itself determining the underlying latent continuous variable.

The final endogenous causal pathway structure corresponding to the model estimation results is shown in Figure 2, and the coefficient estimates are presented in Table 2 in the "Endogenous Effects" section. This structure was determined by testing each direction of causality between each pair of endogenous outcomes and selecting the causal structure among the many outcomes that yielded the best data fit and logical consistency. The prevailing causal structure reveals a chain of recursive effects, beginning with decisions on walking purposes (with the exception of recreational walking) influencing walking frequency. These effects are all positive, with walking for exercise demonstrating the strongest effect on the likelihood of walking frequently, followed by walking for transport, walking at or for work, and walking a pet.

Regarding the endogenous effect of place on walking frequency, only walking in residential areas appears to directly influence walking frequency. This finding aligns with expectations, as an individual's immediate residential environment is likely to shape their outdoor walking activity significantly. Characteristics such as sidewalk availability and continuity, street connectivity, aesthetics, safety, and social presence within the neighborhood can all contribute to an individual's decision to walk (see Wang et al., 2016, and Leung et al., 2018). Chudyk et al. (2015) also emphasize the role of the proximity of residential areas to key destinations, particularly grocery stores, shopping malls, and dining establishments, in encouraging walking among older adults. Additionally, we found that recreational walking directly increases the likelihood of individuals walking in residential areas, parks, malls, waterside, and other outdoor areas. This suggests that recreational walking can be undertaken in a variety of environments, depending on the individual's preferences. On the other hand, walking for exercise appears to specifically impact the propensity for walking in waterside or other outdoor areas, presumably because such areas offer environments suitable for exercise activities (e.g., beach, fitness trails, running tracks, or sports fields).

TABLE 2 Estimation Results of Walking Frequency, Walking Purpose, and Walking Place Model Components (N = 1,667)

Variable (base)		Walking Frequency	Walking Purpose					Walking Place				
			Recreation	Exercise	Transport	Walk Pet	Work	Residential	Park	Mall	Gym/ Indoor	Waterside /Outdoor
Individual Characteristics												
Age (50-64 years)	65 or older			0.12^{*}			-0.27^{***}			0.17^{**}		
Gender (male)	Female	-0.11^{**}	-0.24^{***}				-0.25^{***}		-0.16^{*}	0.18^{*}	0.19^{*}	-0.19^{**}
Race/ethnicity (non-Hispanic White)	Non-white and/or Hispanic	0.14^{***}	-0.16^{***}	0.15^{***}		-0.22^{***}		-0.20^{**}	0.26^{**}	0.37^{***}	0.27^{***}	-0.18^{**}
Education (^)	≤ Highschool		-0.17^{**}	-0.25^{***}			0.21^{***}			0.20^{**}		
	≥ Graduate deg.				0.22^{***}	-0.25^{***}						
Employment (unemployed)	Employed			-0.13^{*}	-0.42^{***}		1.18^{***}	-0.45^{***}				
Household Characteristics												
Household income (^)	< $50,000	0.10^{**}			0.23^{***}						-0.26^{***}	
	≥$100,000		0.18^{***}	0.31^{***}		0.22^{***}	-0.36^{***}	0.27^{***}		-0.34^{***}		
Housing (non-apartment)	Apartment					-0.36^{***}						
Presence of child (none)	At least one	0.21^{***}						0.22^{***}	0.23^{***}			
Region (^)	Mountain		0.22^{*}			0.26^{**}						
	Pacific				0.19^{**}						-0.25^{***}	
	East North Cent.						0.37^{***}					
Endogenous Effects												
Walking purpose (^)	Recreation							0.38^{***}	0.46^{***}	0.26^{***}		0.37^{***}
	Exercise	1.15^{***}										0.65^{*}
	Transport	0.96^{***}										
	Walk pet	0.76^{***}										
	Work	0.86^{***}										
Walking place (non-residential)	Residential	0.99^{***}										
Thresholds/Constants												
Constant		-0.75^{***}	-0.36^{***}	-0.24^{***}	-0.24^{***}	-0.44^{***}	-0.84^{***}	0.60^{**}	-0.90^{***}	-1.22^{***}	-0.89^{***}	-0.77
Thresholds	1|2	0.00										
	2|3	0.87^{***}										
	3|4	1.53^{***}										
	4|5	2.07^{***}										

TABLE 2 (continued)

Variable (base)		Walking Frequency	Walking Purpose					Walking Place				
			Recreation	Exercise	Transport	Walk Pet	Work	Residential	Park	Mall	Gym/ Indoor	Waterside /Outdoor
Correlations												
Walking frequency		1.00	-0.17***	-0.53***	-0.52***	-0.26*	-0.15**	-0.66***	-0.28	-0.08	-0.02	0.06
Walking purpose	Recreation		1.00	0.24***	0.12***	0.10**	-0.14***	0.06	0.35	0.11	0.14	0.31
	Exercise			1.00	-0.13***	-0.09**	-0.22***	0.28	0.21	-0.13	0.20	-0.24
	Transport				1.00	-0.11***	0.05	0.23	0.05	0.43***	0.18	0.23
	Walk pet					1.00	-0.12**	0.37	0.30	-0.14	-0.15	0.10
	Work						1.00	-0.27***	0.01	0.05	-0.11	0.10
Walking place	Residential							1.00	0.12	-0.10	-0.27***	-0.18
	Park								1.00	0.15	-0.09	0.15
	Mall									1.00	0.14	0.15
	Gym/indoor										1.00	0.00
	Waterside/outdoor											1.00

Data Fit Measures

Measure	Proposed Joint Model	Independent Model	Thresholds/Constants-Only Model
Log-likelihood at convergence	-9695.02	-10049.93	-10961.64
Number of parameters	128	73	14
M	114	59	0
BIC	10169.82	10320.71	11013.57
Rho-squared $\bar{\rho}^2$	0.105	0.078	--
Nested likelihood ratio test	--	$LR = 709.81 >>> \chi^2_{55,0.001} = 93.17$	$LR = 2533.2 >>> \chi^2_{114,0.001} = 166.41$
Average probability of correct prediction	0.15	0.07	0.04

Significance levels: * p < 0.15, ** p < 0.10, *** p < 0.05; (^) Base category is not identical across the model equations and corresponds to all omitted categories.

The 11×11 correlation matrix shown in the penultimate section of Table 2 reveals several notable patterns. The correlations between walking frequency and various walking purposes (first row and first six columns) are predominantly significant and negative, contrasting with positive endogenous variable effects described earlier. For instance, the correlation between walking frequency and exercise walking is -0.53, while the endogenous effect of exercise walking on walking frequency is +1.15. This discrepancy can be explained by distinguishing between overall correlations and endogenous outcome effects. The negative correlation reflects relationships due to unobserved factors, suggesting that unobserved elements increasing the likelihood of walking for exercise tend to decrease the propensity of walking frequently. Conversely, after controlling for other variables, the positive endogenous effect represents the "true" causal impact of exercise walking on walking frequency. This phenomenon could arise from confounding unobserved factors that simultaneously encourage exercise walking but discourage frequent walking propensity. Consider the unobserved factor of "physical fitness level" as an example. A high fitness level allows individuals to engage in other exercise-related activities, such as running or cycling, potentially leading to a negative correlation with the propensity to walk frequently. However, people who walk for exercise also have a higher propensity to walk frequently, according to the positive endogenous effect of exercise on walking frequency. If the model had not accounted for correlated unobserved effects and simply used exercise walking as an exogenous variable in explaining the propensity to walk frequently, the "true" causal positive effect of "walking for exercise" on "overall walk propensity" would have been underestimated. That is, motivating individuals to walk for exercise will have a positive overall impact on the overall walking propensity, which would have been underestimated (in fact, vanished in our estimations) if the unobserved correlation effects were ignored. This highlights the importance and value of the joint modeling approach adopted in this study.

Similarly, the submatrix formed by the second to sixth rows and columns, which represents correlations among different walking purposes, also shows mostly significant and negative correlations (with a few exceptions). This indicates that various walking purposes are interrelated, and unobserved factors that increase walking for one purpose tend to diminish walking for other purposes. Given time and energy constraints, this is entirely consistent with expectations, as it is quite unlikely that individuals can find the time and energy to walk for all purposes. In contrast, the correlations between walking frequency or purposes and walking places (columns 7 to 11 across all rows) show fewer significant terms. This suggests a weaker relationship between where people walk and how often or why they walk. The few significant terms can be explained in ways similar to those described above. Finally, the correlations among various walking places (the submatrix formed by columns and rows 7 to 11) also show mostly insignificant terms. Notably, a negative correlation exists between residential and gym/indoor walking, suggesting that unobserved built environment attributes that enhance (decrease) walking in the residential neighborhood contribute to reduced (increased) walking in the gym and other indoor places.

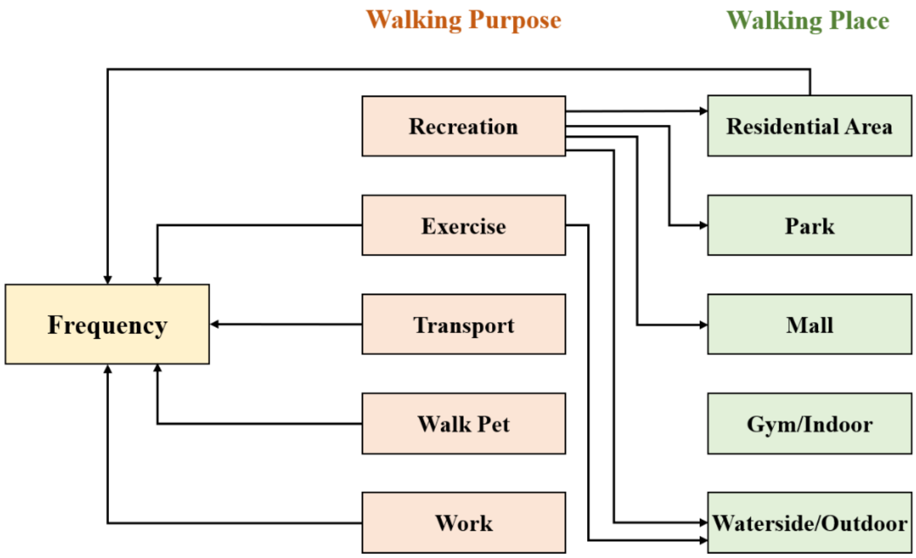

Figure 2 Structure of Endogenous Effects

5.3. Goodness-of-Fit Measures

Goodness-of-fit statistics are computed to compare the fit of the proposed joint model (the MORP model) relative to a naïve independent model that completely ignores jointness and a thresholds/constants-only model. Several metrics can be used for this comparison, as shown in the last section of Table 2. First, the Bayesian Information Criterion (BIC) statistic $\left[= -L(\hat{\boldsymbol{\delta}}) + 0.5 \times (\text{\# of model parameter}) \times \log(\text{sample size})\right]$ is used to compare model performance, where $L(\hat{\boldsymbol{\delta}})$ is the log-likelihood value at convergence. The joint model shows superior performance with a lower BIC of 10169.82 compared to 10320.71 for the independent model and 11013.57 for the thresholds/constants-only model. Table 2 also indicates that the joint model demonstrates a higher average probability of correct predictions (0.15 vs. 0.07 for the independent model and 0.04 for the thresholds/constants-only model) and a higher adjusted likelihood ratio index $\bar{\rho}^2$ (0.11 vs. 0.08 for the independent model). The $\bar{\rho}^2$ index is calculated as follows:

$$\bar{\rho}^2 = 1 - \frac{L(\hat{\boldsymbol{\delta}}) - M}{L(\text{c})} \tag{4}$$

In the above equation, $L(\text{c})$ represents the constants and thresholds-only log-likelihood function at convergence, and M is the number of parameters estimated in the model (excluding the constants and thresholds). Lastly, a nested likelihood ratio test is performed since the joint and independent and thresholds/constants-only models are nested. The likelihood ratio is much higher than the corresponding critical chi-square value at any level of significance when comparing the joint model against either the independent model or thresholds/constants-only model, thus supporting the data fit superiority of the joint model.

6. COMPUTATION OF AVERAGE TREATMENT EFFECTS

Interpreting the effects of variables in complex econometric models can be challenging, especially when dealing with ordinal categories and interconnected outcomes. The coefficients presented in Table 2, while indicative of the impacts of variables on underlying propensities, do not directly translate to estimates of their influence on the ordinal categories themselves (this is particularly the case for the ordinal walk frequency outcome). The model structure also incorporates endogenous outcome effects, creating a complex web of "true" causal and associative influences. To overcome these interpretation challenges, an Average Treatment Effects (ATE) analysis is presented in this section.

As detailed in recent literature by Hwang et al. (2024), an ATE analysis enables the determination of the directionality and magnitude of effects of variables in joint model structures with endogenous relationships. The ATE methodology essentially simulates the impact of changing an independent variable from one state to another, allowing for a more comprehensive assessment of its influence across the sample. For instance, to evaluate the effect of age on walking behaviors, one might compare outcomes between individuals under 65 and those 65 or older. This process involves setting all individuals in the dataset to state A (i.e., the base level), and then using the model estimates to calculate joint probabilities for all possible multivariate combinations of the eleven outcomes. Then, all individuals in the dataset are set to state B (i.e., the treatment level), and the joint probabilities are re-computed. By comparing these probabilities across different states, it is possible to quantify the percent change in behavior attributable to the variable in question. For the walking frequency variable, the ATE represents the percent change in the expected value. For binary outcomes, such as specific walking purposes or places, the ATE reflects the change in the probability of an affirmative response. For a more detailed explanation of ATE computation in this context, please see Hwang et al. (2024), who provide an in-depth discussion of the methodology. The results of the ATE analysis are presented in Table 3.

The top portion of Table 3 provides the percent ATEs (%ATE) corresponding to the exogenous variable impacts, while the bottom portion presents those of the endogenous variable effects. For the ATEs corresponding to the exogenous variables, only total ATEs are reported, reflecting the combination of both the indirect (through endogenous effects) and the direct effects of the variables. To illustrate the interpretation of ATE entries in Table 3, consider the first numeric row corresponding to the age variable. The value of -0.7 in the "Walking Frequency" column indicates that, on average, individuals aged 65 or older walk 0.7% less frequently than those aged 50-64. Similarly, the value of 10.6 in the "Exercise" column suggests that individuals aged 65 or older are 10.6% more likely to walk for exercise compared to the 50-64 age group. Other entries in the table can be interpreted in a similar manner. This section offers an overview of the key findings together with consequent policy implications.

Those 65 and over prefer walking for exercise and in a mall setting, suggesting that providing such walking environments would potentially enhance walking among this group. Women exhibit a lower propensity for walking, walking 9.5% less frequently than men. They are also substantially less likely to walk for recreation and strongly prefer indoor walking environments such as the mall and gym/indoor. This suggests that it would be of value to enhance opportunities for walking that are more integrated within daily activities, given that women may be more time-constrained to engage in walking for recreation. Also, outdoor environments should be enhanced (to be as comfortable and safe as indoor environments) to provide women with more agreeable environments for walking.

TABLE 3 Average Treatment Effects (ATEs)

Variable	Base Level	Treatment Level	Percent ATE (%)										
			Walking Frequency	Walking Purpose					Walking Place				
				Recreation	Exercise	Transport	Walk Pet	Work	Residential	Park	Mall	Gym/ Indoor	Waterside /Outdoor
Individual Characteristics													
Age	50-64 years	65 or older	-0.7		10.6			-21.3			24.3		3.2
Gender	Male	Female	-9.5	-24.3				-18.8	-1.2	-16.8	26.0	28.6	-22.3
Race	White	Non-white	5.1	-18.1	13.9		-23.0		-10.4	34.2	62.0	43.0	-17.1
Education	≤ Highschool	≥ Graduate degree	6.3	18.6	25.5	21.8	-29.5	-15.3	1.0		-28.5		
Employment	Unemployed	Employed	-4.1		-10.7	-34.3		278.3	-20.7				-3.4
Household Characteristics													
Household income	<$100K	≥$100K	15.1	22.7	29.1	-24.1	26.9	-26.6	14.6		-38.0	41.8	12.1
Presence of children	None	At least one	-8.8						11.2	29.1			
Endogenous Variables													
Recreation	No	Yes	9.2						19.5	71.2	36.8		49.5
Exercise	No	Yes	26.4										101.4
Transport	No	Yes	19.8										
Walk pet	No	Yes	14.9										
Work	No	Yes	15.8										
Residential	No	Yes	22.4										

The ATE estimates for the race variable suggest that there may be critical equity issues that affect walking frequency, location, and purpose. Non-white individuals walk 5.1% more frequently, but less so for recreation or walking a pet. They are also less likely to walk in their residential neighborhood or waterside/outdoor areas. This suggests that non-white individuals are experiencing a dearth of safe recreational (outdoor) areas where they can walk for leisure. In addition, their residential neighborhoods appear less conducive to walking for safety and/or infrastructure reasons, as Haddad et al. (2023) also emphasized. Concerted efforts should be made to overcome these barriers. Employed individuals walk considerably less for exercise and transport, reflecting the time constraints they experience due to work and related obligations. Employer fitness and walking programs/challenges may help enhance walking opportunities for employed individuals.

Among household characteristics, higher income is associated with a higher level of walking frequency and greater levels of walking for recreation, exercise, and pet walking. This finding may reflect inherent preferences among individuals of low socioeconomic status to engage in more passive leisure activities, such as watching television, rather than walking (see Beenackers et al., 2012). Higher-income individuals also walk more in their residential neighborhoods, specialized gym or indoor facilities, and waterside/outdoor facilities. These findings clearly indicate the presence of income-related walking disparities, calling for more focused efforts to provide a variety of safe walking environments (beyond the mall) that can serve people of all income groups. Targeted education and marketing campaigns that extol the virtues of walking by framing it as both a leisure activity and a form of exercise and raising awareness of attractive walking facilities/spaces may also help enhance walking among individuals in lower-income households. The presence of children appears to suppress walking levels overall, consistent with the notion that households with children may have time and other constraints that limit their ability to engage in walking episodes. However, they prefer walking in residential neighborhoods and parks. These insights highlight the importance of providing accessible, family-friendly green spaces in close proximity to residences to promote walking among households with children.

Finally, the table provides ATEs for the endogenous variable categories. The results provide compelling evidence for the potential of purpose-driven walking to significantly increase overall walking frequency, particularly when focused on activities close to home. All examined walking purposes exhibited positive endogenous effects on walking behavior, with exercise and transport-related walking demonstrating the strongest associations (percent ATE of 26.4% and 19.8%, respectively). Notably, residential walking, primarily influenced by recreational activity, also contributed substantially to increased walking frequency (the second-highest endogenous effect after exercise, with a percent ATE of 22.4%). In fact, it is the only walking place that directly influences how often people walk, underscoring the importance of the immediate living environment in shaping walking habits.

These findings collectively highlight the importance of creating walking-friendly environments conducive to multiple walking purposes, especially in and around residential areas. This provides a strong case for promoting mixed-use developments, which integrate residential, commercial, and recreational spaces, potentially increasing the likelihood of walking for various purposes within the neighborhood. By enhancing features such as sidewalk availability, street connectivity, and proximity to destinations in residential areas, planners could potentially increase both the frequency of walking and the likelihood of people choosing to walk for exercise, transport, and recreation in their neighborhoods. Furthermore, incorporating accessible green spaces within residential areas could further encourage walking, particularly among households with children.

7. SUMMARY AND CONCLUSIONS

This study provides a comprehensive examination of walking behaviors among older adults by jointly modeling walking frequency, purpose, and place through a multivariate ordered probit (MORP) approach. Utilizing data from the 2022 AARP walking survey, our analysis reveals complex patterns and relationships that significantly contribute to an enhanced understanding of walking behaviors for this demographic.

Study results reveal significant sociodemographic influences on walking behaviors. Age, gender, race/ethnicity, education, employment status, household income, housing type, and household composition all play critical roles in shaping walking patterns. These findings are generally consistent with the results of previous works. Importantly, though, our model estimation results also reveal the complex interplay among walking frequency, purpose, and place, underscoring the need to consider walking behavior as a multidimensional whole rather than the relatively fragmented single-dimensional emphasis of earlier studies. The recursive causal structure among the endogenous outcomes in our research indicates that the choice of non-discretionary walking purposes (such as exercise, transportation, work, and pet walking) significantly drives walking frequency, with walking for exercise exhibiting the strongest positive effect. Choosing to walk in residential areas significantly affects walking frequency, highlighting the critical role of the immediate living environment in shaping walking habits. Conversely, recreational walking strongly impacts the choice of diverse walking places, demonstrating that this walking purpose is versatile and can be fulfilled in a variety of environments.

The results from our multidimensional analysis of walking behavior provide important insights for public health initiatives, urban planning, and policymaking. They suggest that interventions to promote walking among older adults should be tailored to specific sociodemographic subgroups. Addressing disparities in walking behavior is also essential to ensure equitable access to the benefits of physical activity. Study findings emphasize the need for policies and interventions that focus on creating mixed-use walkable environments, particularly in residential areas, and promoting walking for exercise and recreation.

Of course, as with any paper, several study limitations remain that may be addressed in future research. First, a significant limitation is that the dataset used in our analysis lacked residential location information, preventing the inclusion of important built environment variables that affect walking behaviors. Second, future research could benefit from expanding the choice categories to capture a broader range of walking-related choices. This expansion might include more detailed purposes (e.g., shopping, accessing public transit) and additional place types (e.g., community centers, cultural sites). Third, this study relied on a survey that collected walking data based on respondent self-reporting. Future research could benefit from employing diary-type data collection methods that are likely to provide a more detailed and accurate coverage of walking frequency, purpose, and place on a day-to-day basis, potentially revealing patterns that may be obscured in more general surveys that rely on self-reported behaviors. Finally, while the structure of the relationship among the endogenous outcomes presented in this study may be viewed as providing the best overall reflection of causal pathway behavior within the entire sample, it is possible that different population segments follow different causal pathways in the relationship among the endogenous outcomes. Investigating population segmentation to accommodate such heterogeneity across individuals in causal pathways among the endogenous LD outcomes (as in Asmussen et al., 2024) could enhance the development of more customized policy interventions. Of course, even here, from an estimation and sample size standpoint, there would be a need to limit the number of latent segments (representing different causal pathway effects among the 11 endogenous LD outcomes) to about four different configurations taken at one time. Extensive experimentation can be undertaken to determine the mix of (up to about) four causal pathway configurations that best reflects heterogeneity across individuals.

GLOSSARY

- AARP: American Association of Retired Persons
- ATE: Average Treatment Effect
- BIC: Bayesian Information Criterion
- LD: Limited Dependent
- MORP: Multivariate Ordered-response Probit
- NORC: National Opinion Research Center
- POS: Public Open Space

Dependent variables in Tables 2, 3, and Figure 2:

- Recreation: Walking purpose involving leisurely walking/strolling and other recreational activities
- Exercise: Walking purpose for physical exercise
- Transport: Walking purpose to get to and from various destinations (e.g., a friend's house, a store, work, the library)
- Walk pet: Walking purpose to walk a pet
- Work: Walking purpose as part of the person's employment
- Residential neighborhood: Walking place in the person's neighborhood or another residential area
- Park: Walking place at a neighborhood, city, state, or other park
- Mall: Walking place at a mall or shopping center
- Gym/indoor: Walking place at a fitness center, gym, or another indoor space
- Waterside/outdoor: Walking place at a beach, along a river or canal, or in another outdoor space

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