Multivariate Analysis of Walking Habits After COVID-19

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Abstract

Physical activity is essential for maintaining mental and physical health. Despite its benefits, older adults fall short of the recommended physical activity levels. Walking, in particular, offers significant advantages for older adults because of its low-impact nature and lower likelihood of serious injuries. Accordingly, in this study, we examine three key dimensions of walking behavior among adults aged 50 and older: frequency, duration, and social companionship (SC). In particular, using data from a 2022 the American Association of Retired Persons (AARP) Walking Survey, and employing a joint modeling approach, we identify the factors influencing each of the three dimensions of walking behavior. Our findings suggest that older unemployed adults from low-income/minority households, women, and individuals in households with children tend to walk less frequently and for shorter durations. Having social company on walks has the highest positive effect on both walk frequency and duration, dominating over other sociodemographic factors. The results also point to specific population segments; specifically Black individuals, those employed, and single adults; walking less in groups, while those in households with children walking more in a group. These results highlight the importance of considering social aspects in understanding walking behavior. Policy implications of the findings are discussed.

Keywords: older adults, walking behavior, social companionship, multivariate modeling, health equity

1. INTRODUCTION

Physical activity significantly impacts mental and physical health. It reduces the risk of cardiovascular diseases and enhances physical dexterity (see LaCroix et al., 1996, and Oja et al., 2018), while also having the benefit of improving mental health through a reduction in depressive symptoms and enhanced life satisfaction (see Julien et al., 2013, and Franke et al., 2021). Recognizing such physical and mental health benefits of physical activity, 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 (USHHS, 2018). However, data shows that 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 to 64 age group (National Center for Health Statistics, 2019). One reason that older adults lag behind in physical activity is the increased physical frailty with age, making it more difficult for older adults to partake in relatively vigorous physical activities such as running or playing soccer. Besides, older adults tend to be more susceptible to injuries and bone fractures when engaging in strenuous physical activities (see Spiteri et al., 2019). Thus, the Centers for Disease Control and Prevention (CDC) recommends brisk walking as the primary moderate-intensity activity for older adults, which forms the basis for social programs promoting walking in the U.S. and beyond (for example, the "Walk2Connect" in the U.S, the "Choose to Move" in Canada, and the "Walking for Health" in England; see Hanson and Jones, 2015 and Franke et al., 2021).

The 150-minute total walk duration recommendation of physical activity for older adults (assuming that walking is indeed the predominant form of physical activity for this age group) may be achieved through any number of combinations of frequency of weekly walking episodes and duration per walking episode. While the USHHS recommendation does not specify any optimal combination of the two, there is evidence that a good balance and mix of the two is helpful. For example, while walking for 15 minutes per walking bout and ten walking bouts a week, and walking for 75 minutes per bout and two bouts a week, both involve a total of 150 weekly minutes of walking, there are differences in the potential health benefits. The shorter and more frequent bouts are beneficial for regulating blood sugar levels, particularly for those with diabetes or insulin resistance (see Umpierre et al., 2013 for a systematic review assessing the association between intensity and volume of exercise in patients with type 2 diabetes). Moreover, the psychological benefits of walking, such as reduced stress and improved mood, may be more noticeable with frequent bouts spread throughout the day or week. The longer bouts, on the other hand, provide sustained cardiovascular exercise, leading to greater improvements in heart health and endurance and reduction in cholesterol rate compared to the shorter, more frequent bouts (see Vasankari et al., 2017 and Prasertsri et al., 2022). In short, whether a good balance between frequency and duration is preferable or not is not in question, though the "optimal" balance may vary from individual to individual. In this context, it is important to examine both the frequency and duration dimensions of walking episodes when studying walking behaviors. In contrast, most existing studies have either focused solely on bout frequency (see Cerin et al., 2009, Sehatzadeh et al., 2011, Liao et al., 2017, and Hwang et al., 2023), or on the overall duration of walking over a certain period (for example, Klenk et al., 2016, Valenti et al., 2016, and Patel et al., 2018), without examining both aspects simultaneously.

An additional walking dimension that has received some limited attention, albeit more in the public health and gerontology literature rather than the transportation/urban planning literature, is whether a walking bout is undertaken alone or in company. This literature indicates that having a walking companion, especially for older adults, has a positive impact on mental well-being (see

Kritz et al., 2021, and Irvine et al., 2022) and provides motivation to maintain a sustained walking routine (see, Leung et al., 2018, Kubota et al., 2020, Kritz et al., 2021, and Irvine et al., 2022). Thus, relative to walking alone, walking in social company can influence walking bout frequency and duration, as well as enhance quality-of-life benefits (Meads and Exley, 2018). Consequently, a comprehensive understanding of walking habits, especially the interplay among the three dimensions of frequency, duration, and companionship, would be beneficial, particularly in the wake of the COVID-19 pandemic that has brought about significant declines in walking among older adults (see Beauchamp et al., 2022, Felipe et al., 2023, and Hwang et al., 2023). Accordingly, in this paper, we employ a multivariate modeling approach to estimate the effects of sociodemographic factors on all three dimensions, utilizing data from the "American Association of Retired Persons (AARP) Walking Survey: Attitudes and Habits of Adults Aged 50 and Older" collected in July 2022.

The rest of this paper is organized as follows: Section 2 provides an overview of the literature on the walking behavior of older adults. Section 3 discusses the data and sample characteristics, while Section 4 presents estimation results. Section 5 translates the estimation results into average treatment effects (ATEs) that inform policies aimed at promoting walking, as discussed in Section 6. Finally, Section 7 concludes the paper with a summary of the findings and future research directions.

2. LITERATURE OVERVIEW

A number of earlier studies have explored the health and overall well-being benefits of each of the three walking dimensions (i.e. frequency, duration, and companionship) considered in this study. Studies on walking frequency and duration effects have established beneficial effects on improving mental wellness (through decreasing the occurrence and frequency of depression, improving vitality, and reducing stress levels; see, for example, Kroesen and De Vos, 2020, Roe et al., 2020, Chen et al., 2021, and Chin et al., 2022) and physical wellness (through reduced cardiovascular disease risks, enhanced control on blood glucose and pressure; see, for example, Morita et al., 2019, Omura et al., 2019, Yates et al., 2020, and Rizka et al., 2022). Research on the influence of companionship walking, especially among older adults, has also been quite extensive, suggesting reduced loneliness feelings in everyday life, improved functional capability, lower body fat indices, better sleep, and enhanced happiness mood (see, for example, Zhu and Fan, 2018, Gümüş Şekerci and Kır Biçer, 2019, Kritz et al., 2021, and Mizuta et al., 2023). Extensive and relatively recent meta-reviews of the benefits of walking as a physical activity for health and quality-of-life reasons, especially for older adults, are available in Meads and Exley (2018), Bushman (2020), Marquez et al. (2020), Sithichoksakulchai et al. (2022), and Wei et al. (2022).

In the rest of this section, we focus more on the determinants of walking, rather than the now well-established positive impacts of walking on health and quality of life. In this context, ecological models of physical activity in older adults (see, for example, Sallis et al., 2015; Krogstad et al., 2015; Thornton et al., 2017 and Bergen et al., 2023) have identified individual walking behavior as being influenced by the rich interplay of individual characteristics (sociodemographics such as age, race/ethnicity, gender, household composition, and income, and health conditions), psychosocial factors (social support, self-efficacy, and health and safety perceptions), and environment variables (including objective and perceived built environment attributes, weather conditions, and ambient natural greenery/vegetation characteristics). In the following sections, we provide a brief overview of existing studies within this ecological framework of walking, based on the dimension of walking considered (that is, based on walking frequency, duration, and social companionship). Our review is confined to studies that examine walking, rather than the broader category of physical activity in older adults. We also emphasize studies of older adults, as opposed to those considering the entire population, though we do include some general population studies undertaken after the onset of the pandemic in 2020.

2.1. Frequency as Measure of Walking Habits

In the research space focusing on walking frequency among older adults, studies have identified many sociodemographic and built environment (BE) determinants of utilitarian and recreational walking trips. Giehl et al. (2016), from a study in Brazil, reported higher participation in one or more utilitarian bouts (of 10 minutes or more) per week among individuals living in high-population density neighborhoods with good street connectivity and sidewalk availability, but observed that participation in one or more recreational walking bouts (of 10 minutes or more) per week to be primarily (positively) related to the neighborhood income level ("neighborhood" was defined in the Giehl et al. study as corresponding to the census tract of the individual's residence). Complementing these findings, Yun (2019) conducted a systematic review of studies on the BE factors associated with older adults' walking behaviors and reported that utilitarian walking frequency is associated with the physical attributes of the built environment, while recreational walking frequency is more closely linked to the neighborhood's social status. Additionally, Wu et al. (2021) tested non-linear relationships between neighborhood BE variables (a neighborhood was defined as the traffic analysis zone (TAZ) of the individual's residence) and daily walking frequency among older adults in Zhongshan, China. They found significant non-linear effects of population density, bus stop density, land-use mix, and sidewalk density on walking frequency. Wu et al. (2021) also presented associations between personal and household sociodemographic factors and walking frequency among older adults. The results showed that women, those aged 60 to 70 years, and those with a positive attitude toward walking exhibited higher walking frequency, while employed individuals walked significantly less.

During the COVID-19 pandemic, there has been an observable shift in travel behavior, including walking. The long-term effect of the pandemic on walking behavior is the subject of emerging research, though the number of studies on this topic is limited due to the relatively short period available for assessing long-term behavioral changes. However, research conducted by Hwang et al. (2023) and Younes et al. (2023) used reported walking frequency and/or intentions regarding walking frequency to study post-pandemic walking behavior. Hwang used a national U.S. sample, while Younes used a sample collected in New Jersey, U.S. Although both studies did not specifically focus on adults aged over 50 years, their findings suggest that individuals with greater flexibility and resources, such as the ability to work from home and higher income levels, walked more frequently than their peers. Hwang et al. (2023) further provided a comparative analysis of walking frequency before and after the pandemic, noting a decline in walking activity among individuals over 65 years of age. Similar to Giehl et al. (2016), high neighborhood (based on zip-code) population density, good neighborhood walk and bicycle infrastructure, and proximity to the nearest bus stop also turned out to be positive determinants of walk frequency. Additionally, Hwang et al. explored reasons affecting the decisions to walk and found walking to be more motivated by recreation desires than utilitarian pursuits. Younes et al. (2023) used both reported walk frequency during the pandemic (based on surveys conducted in the winters of 2020-2021 and 2021-2022), as well as walk frequency intent in the longer term future. They found that individuals aged over 50 years were less likely to increase walking during the pandemic. However, when considering the desire to walk more after the pandemic in the longer term future, there was no significant difference among age groups, suggesting that older adults may be more inclined to resume or increase their walking habits once pandemic-related health concerns lessen. Work frequency from home (the main exogenous variable of interest) and high incomes also had a positive effect on walking frequency in the immediate aftermath of the pandemic as well as in the context of future walk frequency intentions.

2.2. Duration as Measure of Walking Habits

The emphasis placed by the USHHS and other health organizations on total weekly physical activity duration has led to many studies on weekly walk duration. Nagel et al. (2008), based on their study in Portland in the U.S., found that certain environment factors, such as neighborhood poverty, high volume streets, and good land use mix (based on quarter-mile and half-mile buffers around participants' residences), significantly influenced the walking duration of older adults, although Nagel et al. did not find a significant relationship between BE factors and the decision to engage in walking. They proceed to conjecture that "modifications to the built environment may have little benefit in promoting walking behavior among sedentary older adults." Older age, being white, and having a higher self-efficacy score also increased walking duration. Cerin et al. (2013) investigated the effect of perceived neighborhood BE factors (rather than objective BE measures) on weekly walk duration within their residential neighborhoods (defined as within 15 minutes of walking from the residence). They used data collected from older individuals residing in Hong Kong, and observed that, in general, recreational walking duration within the neighborhood had little association with perceived neighborhood BE factors (including perceptions of pedestrian infrastructure and proximity of recreational facilities). Maisel (2016) also focused on neighborhood BE perception (rather than objective BE measure) effects, but controlled for neighborhood type (classified based on population density into urban, suburban, or rural). They undertook the analysis using univariate Spearman's rank correlations based on surveys of individuals living in senior centers in New York, U.S. Unlike the results from Cerin et al. (2013), Maisel observed that perceptions of low neighborhood crime, good walking/cycling infrastructure, and good traffic safety increased walking duration regardless of neighborhood type, with land-use mix particularly influencing walking duration in suburban neighborhoods and street connectivity particularly impacting walking duration in urban neighborhoods.

Thornton et al. (2017), based on a study in Seattle and Baltimore in the U.S., employed one-mile buffers around participants' homes to construct BE measures. They identified high intersection density, good land-use mixing, and number of recreation centers within the buffer as positive determinants of weekly utilitarian walking duration, but only mixed land-use as a negative determinant of weekly recreational walking duration. Perception of neighborhood walking/cycling facilities, self-efficacy (confidence to walk), positive social support (higher family companionship in walking and more family encouragement for walking), non-Hispanic white race, and not having a driving license were all also associated with an elevated utilitarian walk duration, while self-efficacy, positive social support, non-Hispanic white race/ethnicity, and being on the younger side were the psycho-social and demographic variables increasing recreational walking duration. Zang et al. (2022), like Maisel (2016), also investigated whether BE effects varied by neighborhood type, though using objective BE measures based on buffers around participants' residences and considering socioeconomic status (SES) to characterize neighborhood type. In their study of Chinese neighborhoods in Guangzhou, they observed that street connectivity was negatively correlated with walking duration in areas with low socioeconomic status, while it had no significant effect on walking duration in high-status neighborhoods.

2.3. Companionship as an Influencer of Walking Habits

Beyond walking frequency and duration, walking behavior can also be influenced by social companionship. In a study conducted in Ontario, Canada, Clark and Scott (2016) examined the barriers to walking for a number of population subgroups, and found that "I have no one to walk with" is one of five important barriers for senior citizens (aged 65+ years) (the other barriers included a lack of motivation to walk, poor lighting, high traffic volumes, and dangerous crossings). The authors suggest that companionship offers both a sense of safety from traffic and crime, as well as serves a social purpose. Arroyo et al. (2020) used a dataset from a web-based survey from Valencia, Spain, investigating the importance of companionship in active lifestyle (walking and cycling) behaviors. They found more positive attitudes toward walking when a person had a larger, geographically compact, and deeper (more frequent communications) social network, suggesting again a relationship between companionship and walking behavior. In contrast, Leung et al. (2018) examined the impact of both physical and social environments on walking behavior and concluded that companionship does not significantly influence the daily step count of older adults. In a longitudinal study, Kritz et al. (2021) discovered that older adults walking with peers tended to walk more frequently than those walking alone, with corresponding improvements in their physical health.

In one of the only studies we are aware of that expressly considers companionship effects and neighborhood BE perception effects on individual walk duration (but at the trip level rather than a weekly level), Liu et al. (2020) employed a survey of older adults residing in Dalian, China. Their results revealed an interesting pattern where walking trip duration decreased when combined with other activities, when pursued with a social companion, and when undertaken frequently during the week. Trip walking duration also increased when residents (a) were satisfied with pedestrian walkway facilities, (b) had a positive view of neighborhood aesthetics, and (c) walked in the evening and felt crime safety was quite under control.

2.4. The Current Study

Table 1 synthesizes the many walking studies just discussed. In the table, we do not include review studies, but do include the Hwang et al. (2023) and Younes et al. (2023) studies that have been undertaken after the onset of the pandemic and considered age as an exogenous variable in their walking studies. In addition to the studies discussed earlier, we also include the study by Yang et al. (2022), who applied a seemingly unrelated regression equations system to examine the influence of neighborhood BE factors and sociodemographics on daily walking frequency and duration, accommodating for unobserved correlations (such as weather conditions on the day of survey) between walk frequency and walk duration. Their analysis used a 2015 travel survey from Xiamen, China, from which they selected individuals 60 years of age or over. The definition of a neighborhood in their analysis was at the community level (*shequ*). Their results indicated the strong positive effects of good land-use mix, high intersection density, and proximity to the commercial center on both the dimensions of frequency and duration, as well as revealed significant demographic effects (men, older and more highly educated individuals, those with many household members, and with a driver's license walk less). The correlation between frequency and duration turned out to be positive and statistically significant. While providing good empirical insights, this study's use of a correlated linear regression for daily walk outcomes (with a mean value of 1.11 walk bouts in the day) needs to be viewed with caution.

Table 1. Literature on Walking Behavior of Older Adults

Reference	Walking Metric Used	Data Characteristics				Main Exogenous Variable[c]
		Type[b]	Year	Region	Considers Companionship?	
Nagel et al. (2008)	Weekly duration	RP	2001	Portland, U.S.	No	BE (objective)
Cerin et al. (2013)	Weekly Duration	RP	2007-2008	Hong Kong, China	No	BE (perceived)
Giehl et al. (2016)	Binary[d]	RP	2009-2010	Florianopolis, Brazil	No	BE (objective)
Maisel (2016)	Weekly duration	RP	2013	Erie County, U.S.	No	BE (perceived)
Thornton et al. (2017)	Weekly Duration	RP	2005-2008	Baltimore, Seattle, U.S.	No	BE (objective and perceived)
Liu et al. (2020)	Trip duration	RP	2017	Dalian, China	Yes (as exogenous)	BE (perceived), SD
Wu et al. (2021)	Daily Frequency	RP	2012	Zhongshan, China	No	BE (objective)
Zang et al. (2022)	Total duration	RP	2019	Guangzhou, China	No	BE (objective), SES
Yang et al. (2022)	Frequency /Total duration	RP	2015	Xiamen, China	No	BE (objective), SD
Hwang et al. (2023)[a]	Frequency	RP/SI	2020-2021	United States	No	BE (objective), SD
Younes et al. (2023)[a]	Frequency	SI	2021-2022	United Kingdom	No	Employment status, WFH (or not) during the pandemic

[a] Studies covered walking behavior after the pandemic, but not focused on older adults.
[b] RP = Revealed preference, SI = Stated intention
[c] BE = Built environment, SD = Sociodemographic, SES = Socioeconomic status, WFH = Work from home
[d] The dependent outcome was whether an individual walked 10 minutes or more in the week for utilitarian purposes and for recreational purposes.

In this study, and relative to the many studies summarized in Table 1, we offer a novel analytic lens to understand older adults' walking behaviors. In doing so, we contribute to the extant literature in many salient ways. First, our study uses revealed preference data on the walking habits of older adults from July 2022, at a time when the worst of the pandemic was clearly in the rear-view mirror. Thus, our analysis should be able to provide a more stable and timely characterization of post-pandemic walking behaviors. Our analysis is particularly relevant given the rapidly aging population in the United States (Caplan, 2023). Second, to our knowledge, this is the first study to jointly model walking frequency, duration, and social companionship. Earlier studies, as should be clear from our earlier discussion and except for Yang et al. (2022), consider a single dimension, sometimes using another dimension (such as frequency or social companionship) as an exogenous variable. Third, as again should be obvious from Table 1, most earlier studies have investigated BE effects on walking behavior, ostensibly because BE measures are viewed as the main policy lever for planners to promote walking. However, in the aftermath of the pandemic, when fundamental walking behaviors have shifted, the role of sociodemographic variables and social companionship considerations should not be underplayed. In fact, a better understanding of individual and companionship factors can provide fundamental insights that promote walking in the post-pandemic era and inform the design of sustainable urban systems. Besides, as indicated by Paydar and Fard, (2021), "…..the previous studies on walking behavior mostly focused on the contribution of built environment to walking behavior, whereas the role of socio-demographic as well as social factors in improvement of walking behavior has been less studied".[1]

Figure 1 illustrates the conceptual/analytic framework used in the paper. Exogenous variables, representing individual and household sociodemographic characteristics, are located on the left side of Figure 1. As part of our joint system, we estimate alternative directions of recursivity among the three walking measures (for a total of six possible recursive configurations) and obtain the one that outperforms the others based on data fit considerations (more on this in Section 4.3).[2] The final recursive configuration in our analysis indicated that walking frequency has a direct effect on walking duration, while companionship influences both walking frequency and the average duration of walking sessions. These endogenous effects are the ones represented (by the bold lines) on the right side of the figure within the box labeled "walking outcomes." The dashed lines within the same box characterize correlations between the outcome variables.

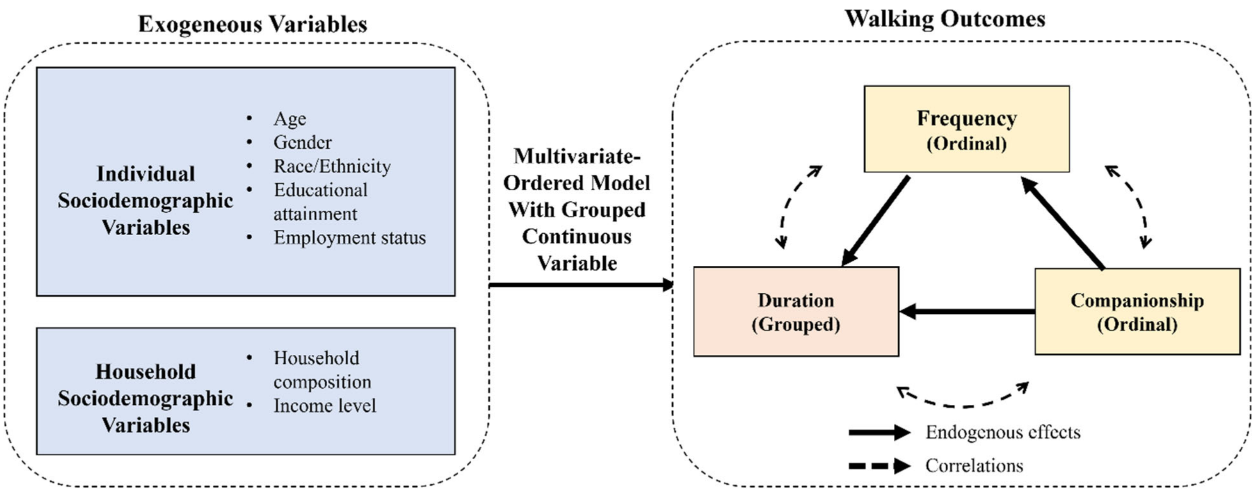

Figure 1. Relationship between Exogenous Variables and Walking Outcomes

[1]Further, most studies considering BE measures ignore the potential endogeneity of these measures to walking behavior. This is particularly important when using cross-sectional data, because of the potential comingling of "true" BE effects with a spurious associative effect originating from the non-random assignment of individuals to residential locations. Bhat and Guo (2007) discuss this residential self-selection issue at length. More recent studies that establish the presence of such self-selection effects include Van Wee, 2009; Van Acker et al., 2014; Bhat et al., 2016, and Bhat, 2024. Guan et al., (2020) provides an exhaustive review of this self-selection literature. In this study, we steer clear of these issues by not considering any BE measure as an exogenous variable. In any case, BE measures cannot be constructed in our study, because, other than the Census Division (and Region) of residence, no other geo-location identifier of an individual's residence was collected in the AARP survey. But, as indicated earlier, the AARP survey is a timely and rich source of walking behavior of older adults in the aftermath of the pandemic.

[2]In joint limited dependent variable models such as the one estimated in the current paper, logical consistency considerations allow only one-way recursive effects, where the observed value of one endogenous variable can influence the underlying propensity of another endogenous variable, but not vice versa. This is discussed in detail in (Bhat, 2015).

3. METHODOLOGY

3.1. Survey

This study utilizes data from "AARP Walking Survey: Attitudes and Habits of Adults Aged 50 and Older" (AARP, 2023). The survey collected data from 1,691 U.S. adults aged 50 and older via the National Opinion Research Center (NORC)'s Foresight 50+ panel.[3] The survey was conducted between July 21 and July 26, 2022, a period characterized by widespread vaccination, and the lowest COVID-related death and hospitalization rates since the beginning of the pandemic. Additionally, at the time of data collection most of the restrictions, including the mandatory wearing of face masks and social distancing, had been lifted, allowing people to return to normal daily life (Phillips, 2022). Following extensive data cleaning and the removal of erroneous entries, 1,667 observations were retained in the final sample.

3.2. Exogenous Variables

The exogenous variables are grouped into individual and household characteristics. Additionally, we also considered regional residence within the U.S. to capture heterogeneity in weather and social environment.[4] Individual-related factors include age, gender, education level, employment status, and race. Household characteristics include household income, marital status, and household composition. Benchmark data from NORC's report, derived from the U.S. Census Current Population Survey (CPS) and the American Community Survey, were used to determine the sample's representativeness of the broader 50+ U.S. population, as depicted in Table 2 (AARP and NORC, 2022). There was a deliberate oversampling of individuals of non-white origin in the NORC survey, as evidenced in the 44.8% of white, non-Hispanic individuals relative to the corresponding census statistic is 70.7% for individuals aged 50 and over), and the clear over-representation of individuals of non-Hispanic Black, non-Hispanic Asian, and Hispanic origin. The comparisons also reveal an over-representation of (a) senior individuals (65 years or older), men, individuals with middle and higher levels of education, employed individuals, and never-married individuals, and (b) households with a middle-income level and those living with children (a child was defined in the survey as an individual less than the age of 18 years).

In estimation, we use the unweighted sample, given our focus is to estimate individual-level relationships of the effect of changes in exogenous variables on the endogenous outcomes. Thus, the main consideration relates to whether the sampling strategy is endogenous or exogenous to the modeled outcomes. Because our sample corresponds to exogenous sampling, we use the efficient and consistent unweighted approach (see also Wooldridge, 1995 and Solon et al., 2015).

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[3] Additional details of the survey administration and methodology are available at https://www.aarp.org/pri/topics/health/prevention-wellness/walking-attitudes-habits-adults-50-older/. Accessed June 6, 2024.

[4] The regions were defined based on the nine US Census Divisions of New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain and Pacific. Further, these divisions were aggregated into four Census Regions: Northeast, South, West, and Midwest. Interestingly, while our sample had ample representation from each Census Division and Region, these geographic dummy variables (with one of them being the base category) did not turn out to be statistically significant even at the 80% confidence level, after controlling for the socio-demographic variables. That is, after controlling for socio-demographics, no heterogeneity based on geography of residence (at least captured in the form of Census Divisions and Regions, as available in the AARP walking survey) was observed in any of the three walking outcomes considered in the current paper. Thus, in the rest of this paper, we do not raise the issue of geographic location residence.

Table 2. Sample Distribution of Exogenous Variables (N = 1,667)

Variable	% in Sample	% in Benchmark (2021)
Age		
50-64	43.4	52.1
65 and above	56.6	47.9
Gender		
Women	47.9	52.8
Men	52.1	47.2
Education		
High school or less	23.2	40.8
Some college or Bachelor	62.2	44.9
Some graduate degree	14.6	14.3
Employment status		
Employed	48.1	45.3
Retired/Not employed	51.9	54.7
Race		
White, non-Hispanic	44.8	70.7
Hispanic	22.9	11.7
Black, non-Hispanic	21.6	10.7
Asian, non-Hispanic	9.7	5.4
Others	1.0	1.5
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
Household composition		
No child	81.9	86.4
Live with a child (“child” is defined as an individual less than 18 years of age)	18.1	13.6

3.3. Walking Outcome

The walking (dependent) outcomes in this study include the number of days per week spent walking for more than ten minutes at a time (also referred to as walking frequency), the average daily walking duration on days walked (also referred to as walking duration), and the propensity to walk with others (also referred to as walking companionship). The outcomes were constructed based on the respondents’ answers to the following survey questions:

- Frequency of walking: "In a typical week, how many days do you walk for at least 10 consecutive minutes, regardless of the reason?" (Response options include Never, 1-2, 3-4, 5-6, or 7 days per week).

- Daily walking duration: "On days when you walk, approximately how many minutes do you spend walking on average?" (Response options include 10, 11-29, 30-59, or 60 or more minutes); for ease, in the rest of this paper, we will refer to this dimension simply as "walking duration."
- Social companionship: "In general, when you walk for any reason, how often do you walk with someone else?" (Response options include Never, Rarely, Sometimes, Often, Always); for ease, in the rest of this paper, we will refer to this dimension simply as "SC."

The 10-minute walking duration is especially relevant as it aligns with the World Health Organization's (2010) recommendation that aerobic activity should be performed in bouts of at least 10 minutes[5]. Respondents who reported never walking more than ten minutes per day were not asked about their walking duration and social companionship. Table 3 shows the distribution of the three outcome variables. Responses were predominantly concentrated around the mid-level options for all three questions, yet each level retained a sufficiently large number of observations.

Table 3. Distribution of Outcome Variables

Walking frequency (weekly)	**(N=1667)**	**Walking duration (per day of walking)**	**(N=1352)**	**Social Companionship (SC)**	**(N=1352)**
Never	315 (18.9%)	10 minutes	159 (11.7%)	Never	160 (11.9%)
1-2 days/week	285 (17.1%)	11-29 minutes	538 (39.8%)	Rarely	437 (32.3%)
3-4 days/week	466 (27.9%)	30-59 minutes	447 (33.1%)	Sometimes	441 (32.6%)
5-6 days/week	353 (21.2%)	60 or more minutes	208 (15.4%)	Often	222 (16.4%)
7 days/week	248 (14.9%)			Always	92 (6.8%)

3.4. Mathematical Formulation

To account for potential interdependencies among the different dimensions of walking behavior, we employ a multivariate modeling approach. For walking frequency and companionship, ordered-response probit models are used, which assume flexible thresholds and latent variables without direct physical interpretations of the underlying latent variables. However, walking duration is treated differently from the other two outcomes, because it is a continuous variable measured in grouped form. Thus, for duration, we apply a grouped continuous model with fixed thresholds using an unobserved underlying latent variable that represents the individual's continuous walking duration. Note, however, that because we assume a normal distribution for the error term in the grouped model, the unobserved underlying latent variable is considered as ln(walking duration), so that it can range over the entire real line. This also assures that predictions of the continuous walking duration will always be positive.

[5] For full transparency, we should note that the latest World Health Organization guidelines on physical activity and sedentary behavior (Bull et al., 2020) have removed the minimum bout duration recommendation of 10 minutes.

In the following presentation, we suppress the notation q for individuals, and derive the likelihood contribution for each individual q. Also, we develop the estimation procedure for the case when all three outcomes are available. In cases where respondents indicated that they never walked on any day of the week for more than 10 minutes, it stands to reason that their walking duration is shorter than 10 minutes. However, social companionship is not relevant for "never" walkers; so, for "never" walkers, the procedure below needs to be modified to consider only the marginal bivariate probability of frequency and duration. Next, following notations from Bhat et al., (2010) and Bhat, (2018), let i be an index for outcome ($i = 1,2,\ldots, I$; in this study, $I = 3$). Also, let the ordered-response (grouped-response) level for outcome i be $m_i \in \{1, 2, \ldots, K_i\}$, where K_i is the highest level corresponding to variable i. In conventional ordered response formulation,

$$y_i^* = \boldsymbol{\beta}_i' \mathbf{x} + \varepsilon_i, y_i = m_i \text{ if } \theta_i^{m_i - 1} < y_i^* < \theta_i^{m_i}, \tag{1}$$

where $\mathbf{x}$ is an $(L \times 1)$ vector of exogenous variables (including a constant) as well as possibly the observed values of other endogenous variables, $\boldsymbol{\beta}_i$ is a corresponding $(L \times 1)$ 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, and $\theta_i^{m_i}$ is the upper bound threshold for level m_i, satisfying $\theta_i^0 < \theta_i^1 < \theta_i^2 \ldots < \theta_i^{K_i - 1} < \theta_i^{K_i}$; $\theta_i^0 = -\infty$, $\theta_i^{K_i} = +\infty$ for each outcome i. Assume that the first outcome is frequency (y_1^* is the underlying latent propensity for walking that is mapped to the observed ordered-response weekly frequency y_1 through the thresholds), the second is duration (y_2^* corresponds to the unobserved continuous natural logarithm of walking duration, which is observed in the coarsely censored grouped form of y_2), and the third is social companionship (SC) (y_3^* is the underlying latent propensity for group walking that is mapped to the ordered-response outcome y_3 through the thresholds). The thresholds for the second outcome are $\theta_2^0 = -\infty$, $\theta_2^1 = \ln(10 \text{ minutes})$, $\theta_2^2 = \ln(30 \text{ minutes})$, $\theta_2^3 = \ln(60 \text{ minutes})$, and $\theta_3^4 = +\infty$. (the thresholds for the first and third outcomes are to be estimated). The variance of ε_2 (say σ_2^2) is estimable, while the variances of ε_1 and ε_3 (for the ordered-response frequency and SC outcomes) are normalized to one for identification purposes. The ε_i terms are normalized to have zero mean (this zero mean normalization implies that the $\boldsymbol{\beta}_2$ vector element on the constant in $\mathbf{x}$ for the duration outcome needs to be estimated, while the corresponding $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_3$ vector elements on the constant in the $\mathbf{x}$ vector element have to be normalized to zero, because the underlying locations of y_1^* and y_3^* for the ordered-response outcomes are not identifiable). Then, $\boldsymbol{\varepsilon} = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_I)'$ follows a multivariate normal distribution with an $(I \times 1)$ mean vector of zeros $\mathbf{0}_I$ and an $(I \times I)$ covariance matrix $\boldsymbol{\Sigma}$, as follows (for our empirical application):

$$\boldsymbol{\varepsilon} \sim MVN_I\left[\mathbf{0}_I, \boldsymbol{\Sigma}\right], \text{ or } \boldsymbol{\varepsilon} \sim MVN_I\left(\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \sigma_2 \times \rho_{12} & \rho_{13} \\ \sigma_2 \times \rho_{12} & \sigma_2^2 & \sigma_2 \times \rho_{23} \\ \rho_{13} & \sigma_2 \times \rho_{23} & 1 \end{pmatrix}\right)$$

ρ_{12} corresponds to the correlation in the error terms underlying the latent continuous variables between the frequency and duration outcomes, ρ_{13} is the corresponding correlation between the frequency and SC outcomes, and ρ_{23} is the corresponding correlation between the duration and SC outcomes. 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 $\boldsymbol{\theta}_i = (\theta'_{i,1}, \theta'_{i,2}, ..., \theta'_{i,K_i-1})'$ and vertically stack all $\boldsymbol{\theta}_i$ vectors for the ordered-response outcomes (i=1 and i=3 for our empirical analysis) into a single vector $\tilde{\boldsymbol{\theta}}$. Let the individual under consideration select level k_i (i = 1,2,.., I). Stack the lower thresholds θ_{i,k_i-1} corresponding to the observed values of the individual into an $(I \times 1)$ vector $\boldsymbol{\theta}_{low}$, and the upper thresholds θ_{i,k_i} into another $(I \times 1)$ vector $\boldsymbol{\theta}_{high}$. Also, stack the y_i^* latent variables into an $(I \times 1)$ vector $\mathbf{y}^*$. Then, in matrix form, the latent propensities underlying the observed multivariate outcome for the individual should satisfy :

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

Lastly, define a vector $\boldsymbol{\delta}$ that holds the collection of parameters to be estimated: $\boldsymbol{\delta} = \left(\left[\text{Vech}(\boldsymbol{\beta})\right]', \tilde{\boldsymbol{\theta}}', \left[\text{Vechup}(\boldsymbol{\Sigma})\right]' \right)'$, where the operator "Vech(.)" row-vectorizes all the non-zero elements of the matrix/vector on which it operates, and the operator Vechup(.) row-vectorizes the (estimable) upper diagonal elements of a matrix. Then the likelihood function of a single individual may be written as:

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

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 MVN density function of dimension I with a mean of $\boldsymbol{\beta}'\mathbf{x}$ and a correlation matrix $\boldsymbol{\Sigma}$. A maximum likelihood inference approach is used in estimation. The log-likelihood function for a sample of Q decision-makers is obtained as the sum of the individual-level log-likelihood functions.

4. EMPIRICAL RESULTS

This section presents the model estimation results for the three outcomes of interest in the study. A variety of functional forms and combinations for the explanatory variables were examined, with the final model selection based on statistical significance and parsimony considerations. Table 4 presents the estimation results. In Table 4, a positive coefficient for an exogenous variable indicates that individuals with the corresponding characteristic have a higher propensity to walk frequently, have longer walking durations, and have a higher propensity to walk with others. Conversely, a negative coefficient suggests that individuals with higher levels of that exogenous variable have a lower inclination to walk frequently, have shorter walking duration, and have a lower inclination to engage in walking with others. A "--" in Table 4 is used to signify that a variable is not statistically significant at the 95% confidence level. Note that the values reported in the "Thresholds" panel for frequency and companionship in Table 4 do not have any substantive interpretations on their own. These thresholds serve solely as a mapping mechanism to translate the underlying propensity to the actual observed ordinal category. For duration, the thresholds are fixed based on the brackets provided in the survey, as discussed in Section 3.4. Additionally, the duration model includes a constant term, as discussed earlier. Technically speaking, the coefficients in Table 4 correspond to the effects of exogenous variables (and the endogenous SC and walk frequency effects) on the logarithm of duration, but, for presentation ease, we will refer to ln(duration) simply as duration in the interpretation of results. Finally, the effects of exogenous variables on the frequency dimensions reflect direct effects after accounting for any indirect effects of the variables through the SC dimension, while the effects for the duration dimension reflect direct effects after accounting for the mediating effects through the SC and frequency dimensions.

Table 4. Estimates of Exogenous Variables on Outcome Variables

Exogenous variables (base)	Frequency		Ln(Duration)		Social Companionship	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Individual Characteristics						
Age (base: 50-64 years old)						
65 years or older	-0.109	-2.26	-0.147	-2.89	--	--
Gender (base: Man)						
Woman	-0.143	-3.15	-0.160	-3.21	--	--
Race/Ethnicity (base: Non-Black)						
Black	--	--	--	--	-0.171	-2.89
Employment status (base: Retired or not employed)						
Employed	0.125	2.67	--	--	-0.150	-2.78
Household Characteristics						
Household composition (base: Two adults without child)						
Single adult without child	--	--	--	--	-0.283	-4.89
Three or more adult without child	--	--	-0.119	-1.89	--	--
Single adult with child			--	--		
Two adults with child	-0.204	-3.30	--	--	0.257	3.39
Three or more adults with child			-0.218	-2.42		
Household income (base: < $100,000)						
$100,000 or higher	0.092	1.69	0.149	2.51	--	--
Endogenous Effects						
Companionship (base: Walk with others sometimes or less)						
Walk with others - often or always	1.254	14.19	1.179	10.57	--	--
Frequency (base: Never walk or less than two days a week)						
Walk more than three days a week	--	--	0.374	5.26	--	--
Variance	--	--	0.988	29.20	--	--
Correlations						
Frequency	1.00	--	0.66	24.54	-0.57	-15.98
Duration	--	--	1.00	--	-0.44	-11.28
Companionship	--	--	--	--	1.00	--
Constant	**--**	**--**	2.611	37.89	**--**	**--**
Thresholds	**Coef.**	**t-stat**	**Coef.**	**t-stat**	**Coef.**	**t-stat**
1|2	-0.682	-9.98	2.303(ln10)	--	-1.444	-23.30
2|3	-0.076	-1.35	3.401(ln30)	--	-0.514	-10.26
3|4	0.575	10.29	4.094(ln60)	--	0.391	6.97
4|5	1.147	18.65	--	--	1.210	17.75

4.1. Influence of Exogenous Variables on Walking Frequency, Average Walking Duration, and Walking Companionship

The results in Table 4 show that individuals 65 years of age or older and women display a lower walk propensity and duration than those between the ages of 50-64 years and men, respectively. The age result is the reverse of the result found in some studies from the pre-pandemic literature, including Nagel et al. (2008) and Thornton et al. (2017), but harmonious with other findings predating the pandemic (see, for example, Paul et al., 2015, National Center for Health Statistics, 2019, and Liu et al., 2020). It is also consistent with the results from Hwang et al. (2023) and Younes et al. (2023) conducted after the onset of the pandemic. This result may be due to overall safety concerns, less confidence in one's walking abilities, and declines in physical fitness with age. Clark and Scott (2016) also identified the lack of social companionship (SC) as a walking barrier for older adults. The gender result appears more consistent with the pre-pandemic and after-COVID literature (see, for example, Rišová and Sládeková Madajová, 2020; Hwang et al., 2023; Rodrigue et al., 2024), perhaps a reflection of heightened harassment and security concerns.

Black and employed older adults appear to have a lower propensity to walk with others. Although literature examining the relationship between walking companionship propensity and race is limited, previous studies by Wen et al. (2007) and Yi et al. (2016) have reported that Blacks do not exhibit a positive correlation between neighborhood social cohesion and aerobic physical activity.[6] The disinclination of employed older adults to walk in company may be due to challenges in coordination given work schedules. Employment status also directly and positively influences the propensity to walk frequently, though this effect is tempered through the negative indirect effect through SC on walk frequency (SC impacts both walking frequency and walking duration positively, as we discuss later; the net effect of employment status on walk frequency will be individual-specific, though we provide a sense of the magnitude of this net overall effect in Section 5). Regardless, the positive direct employment status effect on walk frequency propensity is still intriguing, and contrary to the findings of overall population studies suggesting that employment constrains the time for pursuing walking and other physical activities (see, Li et al., 2019 and Hwang et al., 2023). But one possible explanation for our result in older adults specifically is that employment may be viewed as a kind of social participation that promotes social networks and social support (Ihara et al., 2022), and thus provides for more self-efficacy and confidence in older adults to pursue walking and other physical activity.

Older adults living alone have the lowest propensity to walk with a companion relative to their peers in other household arrangements, which is intuitive given the absence of another adult or child who could serve as a walking companion. On the other hand, the propensity to walk with one or more companions is highest among older adults with children, much higher than older adults in any other family arrangement without children. Adults with children in the household are likely to pursue joint activity participation in outdoor family activities as a caregiver and more (Colley et al., 2019). Additionally, individuals living in households with children have a lower propensity of frequent walks, though this is tempered by the indirect positive effect of the higher propensity to partake in group-walking. The direct negative effect of children on the propensity to walk frequently is possibly a reflection of time constraints associated with childcare responsibilities (see Aliyas, 2020). Finally, older adults with three or more adults in the household (including the older adult) tend to walk for shorter durations, with this negative direct effect being even stronger in the

[6] Neighborhood social cohesion refers to the sense of trust, belonging, and closeness shared among neighbors in a community. Higher social cohesion generally means people feel more connected to their neighbors (Wen et al., 2007, and Yi et al. 2016).

presence of a child. However, again this direct negative effect for the case of three adults with a child is tempered by the indirect positive effect through the SC dimension. Overall, these results suggest that older adults in households with three or more adults, with or without children, have a lower walk duration per day. The family science literature (see, for example, Van Der Meer, 2008) does suggest that older adults, when having adequate human company within the home, have less motivation to venture out of the home for any kind of social contact, which may, at least in part, explain this result.

With respect to socioeconomic status (SES), older adults in high-income households (annual income of $100,000 or more) exhibit both a greater propensity to walk frequently and for longer durations. This aligns with previous research by Kamphuis et al. (2009) and Stalsberg and Pedersen (2018). Those with higher incomes have the luxury of time and resources to allocate toward recreational pursuits, including walking. Additionally, this income effect may simply be capturing the disparity in the quality of the walking infrastructure between neighborhoods with high-income households and low-income households. In summary, while quantitatively measured walkability appears to be higher in lower SES neighborhoods as a result of high population density (see Bereitschaft, 2017), the perceived quality of walking infrastructure, such as pavement condition, sidewalk continuity, and aesthetics along sidewalks, has been consistently noted to be worse in lower SES neighborhoods (see Sallis et al., 2011, and Zandieh et al., 2016). This outcome highlights how income disparities not only contribute to active living considerations, but then permeate further into public health disparities because of the strong connection between physical activity and mental/physical wellness.

4.2. Endogenous Effects and Variance/Correlations

Moving on to the endogenous effects, as discussed in Bhat (2015), in a joint limited dependent variable model system, the causal relationship between endogenous outcomes cannot be bidirectional, where an observed endogenous outcome A affects outcome B and also outcome B affects outcome A. Additionally, cyclical relationships, where outcome A affects B, B affects C, and C, in turn, affects A, are not permissible. In the study, there are six possible combinations of endogenous relationships. By testing all six possible structures, we arrive at the preferred endogenous pathway of effects in Table 4. The strong causal effect of SC on frequency and duration (after controlling for unobserved factor effects, as discussed earlier in this section) is consistent with empirical programs that have attempted to increase walking through social engagement, and provides a strong justification for considering companionship in research on walking behavior. The other significant endogenous effect from frequency on duration is supported by the study of Duncan et al. (2010), which found that exercise frequency is motivated by both integrated (i.e., "I exercise because it is consistent with my values") and identified (i.e., "It is important for me to exercise regularly") regulations, while long exercise periods are motivated by identified regulations only. Therefore, "Frequent walkers" are more likely to be "Long walkers" than the opposite.

The variance of the error term for the ln(walking duration) dimension (σ_2 in Equation (2)) is estimated to be 0.988. The row panel labeled "correlations" in Table 4 indicates highly statistically significant correlation effects, supporting the notion that the three walking dimensions are chosen as a package (the endogenous effects discussed in the previous paragraph are after controlling for these unobserved correlation effects). The results reveal that unobserved factors that increase SC predisposition also decrease walk frequency propensity ($\rho_{13} = -0.57$) and decrease walk duration ($\rho_{23} = -0.44$). For example, individuals who are extroverted may be the ones who enjoy group walking, but also intrinsically prefer inactive leisure pursuits (rather than being physically active) to maximize social time and conversations. Equivalently, individuals who are introverted may prefer to partake alone in walking as a means of refreshment and solitude (and an escape from what they may view as banal social chatter; see Veitch et al., 2020). Further, if such unobserved negative correlations are not considered, they would incorrectly manifest themselves as a negative endogenous SC effect on walk frequency and duration. That is, the "true" causal positive SC effects on walking frequency and duration that we obtained, as discussed earlier, would get underestimated or even be potentially completely overturned. Similarly, our results show a strong positive correlation effect between the error terms for frequency and duration ($\rho_{12} = 0.66$). This suggests the presence of unobserved individual factors, such as an intrinsic active lifestyle preference, that elevates both walking frequency and duration simultaneously; thus, "Outdoorsy" individuals will enjoy spending time often outdoors and also tend to walk for longer durations.

4.3. Goodness-of-Fit Measures

We assess the performance of our proposed multivariate model, by conducting a comparative analysis against (i) an independent model that disregards correlations, and (ii) a constants-only model, which has only thresholds for frequency and SC, and constant and variance for duration. Several metrics can be used for this comparison. The Bayesian Information Criterion statistic, defined as $\left[\text{BIC} = -L(\hat{\boldsymbol{\delta}}) + 0.5 \times (\#\text{ of model parameter}) \times \log(\text{sample size})\right]$, where $L(\hat{\boldsymbol{\delta}})$ is the log-likelihood value at convergence, indicates superior model performance for the joint model due to its lower BIC value compared to the independent and thresholds-only models. Moreover, the higher values of the average probability of correct prediction and the adjusted likelihood ratio index $\bar{\rho}^2$ for the joint model reflect its improved performance compared to 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-only log-likelihood function at convergence and M is the number of parameters estimated in the model (excluding the constants and thresholds). We are also able to statistically compare the data fit performance of our multivariate model with that of the independent model and the constants-only model using nested likelihood ratio tests. More intuitively, we compare the models using the average probability of correct prediction. The results, shown in Table 5, reveal that our proposed multivariate model outperforms the independent model on all the likelihood-based tests, as well as has a better average probability of correct prediction.[7] Notably, the likelihood ratio test rejects the independent model at literally the 0.000001 level; that is, the probability that the superior performance of the multivariate model could have been a chance occurrence is almost zero.

[7] Note that, while the average probability of correct prediction may seem low, this is because of the multivariate nature of our model. For almost all individuals in our sample, there is a total of 100 combinations of the frequency, duration, and social companionship dimensions; a random prediction model would have an average probability of correct prediction of the order of 0.01.

Table 5. Data Fit Measures

Summary Statistics	Multivariate model	Independent model	Constants-only model
Log-likelihood at convergence	-6219.08	-6400.17	-6879.38
Number of parameters	30	27	10
Bayesian Information Criterion (BIC)	6267.41	6443.67	6895.49
Adjusted likelihood ratio index ($\bar{\rho}^2$)	0.093	0.067	--
Likelihood ratio test versus multivariate model	--	LR=362.18>> $\chi^2_{(3,0.000001)}=30.66$	LR=1320.60>> $\chi^2_{(20,0.000001)}=65.42$
Average probability of correct prediction	0.024	0.022	0.016

5. AVERAGE TREATMENT EFFECTS OF EXOGENOUS VARIABLES

The coefficients corresponding to the variables presented in Table 4 represent effects on underlying scale-less and location-less propensities for the frequency and SC dimensions, though they have a more tangible interpretation as effects on the logarithm of walking duration for the duration dimension. For the frequency and SC dimensions, therefore, the actual effects of variables on the ordinal categories are not obvious from the estimates. Besides, there are endogenous outcome effects, which implies that the total effect of an exogenous variable will be a combination of the direct effect of the variable on a specific outcome as well as indirect effects of the variable through the endogenous effects of other outcomes. These indirect pathways of influence, along with the correlations among the outcomes and the structure of the ordered-response/grouped models, introduce non-linearities, making it challenging to interpret the overall magnitude and directionality of effects solely based on the coefficient estimates in Table 4. To fully understand the overall impacts, including both direct and indirect effects, and to compare the relative magnitudes of these different effect pathways, an Average Treatment Effect (ATE) analysis is undertaken. The ATE analysis also allows the examination of "counterfactual" outcomes, which represent scenarios that are not directly observed in the survey data. For instance, it can estimate the intended companionship preference for individuals who reported never walking for more than ten minutes, even though this scenario is not captured in the survey.

The ATE computation procedure starts with computing, for each individual, the multivariate probability predictions for each of the 100 multivariate combination outcomes of the walking dimensions (total possible combinations=5×4×5= 100, including counterfactual outcomes). Then, for each individual, we compute the expected outcome for each of the three dimensions. For frequency, since the proportion of each level (never (or zero), 1-2 days/week, 3-4 days/week, 5-6 days/week, and 7 days/week) is known, the expected value is calculated by weighting the probability of each level with the mid-point value of each level (so, we assume 1-2 days per week represents 1.5 days a week and so on). For duration, the expected value in walking minutes is conveniently computed as $\exp[\boldsymbol{\beta}_2'\mathbf{x} + (\sigma^2/2)]$. For companionship, where the levels are not obvious, we collapse the SC ordered-response into a binary outcome of SC often/always (which we will view as "yes" for the SC dimension) and SC never/rarely/sometimes (which we will view as "no" for the SC dimension). Lastly, the ATEs are quantified as the change in the expected walking frequency and duration, and the share of the "yes" category for the SC dimension, due to a change in the state of an antecedent variable from a base level "BL" to a treatment level "TL". For example, to estimate the treatment effect of age, the BL would represent individuals between 50 and 64 years, while the TL could represent individuals aged 65 years or above. To compute the ATE, all individuals in the dataset are first assigned to the BL, individual-level expected outcomes for each dimension are computed based on the model estimates, and averaged across all individuals in the sample to obtain (a) average walking frequency per week across all individuals, (b) average walking duration per day across all individuals, and (c) shares of individuals with “yes” on the SC dimension. Then, all individuals are assigned to the TL, and the same procedure is adopted. The percentage changes in the outcomes between levels TL and BL provide the magnitude and direction of the impact of the age variable on walking frequency, duration, and companionship.

Besides the total ATEs, our analysis allows us to quantify and compare the direct effect of an exogenous variable on an endogenous outcome with its indirect effect mediated through other upstream endogenous variables. Distinguishing between direct and indirect effects entails tracing the "pathways" through which exogenous variables affect each dimension of walking behavior. To do so, we compute the direct effect of an exogenous variable X on a specific outcome Y by maintaining all values of other exogenous variables (as well as other endogenous outcomes affecting the outcome Y of interest) as they are in the data and evaluating the treatment effect only on Y. By subtracting the direct effect from the total ATE, we obtain the indirect effects. A straightforward extension applies to the case of partitioning the total effects of exogenous variables on duration, accounting for indirect effects through multiple upstream endogenous outcomes.

The results of the ATE analysis are presented in Table 6. The ordering of the outcomes is slightly different from that in Table 4 because of the causal pathway effects starting from SC to frequency and duration, and from frequency to duration. The exogenous variable effects on SC are straightforward, and represent direct effects. There are three sub-columns under the SC main column. Thus, consider the effect of employment on SC. The entry of “Retired or not employed” under the BL column indicates that, on average, the probability that an unemployed individual walks with a companion (defined for purposes of ATE computations as often or always) is 0.33, while the entry of “Employed” under the TL column shows that, on average, the probability that an employed individual walks with a companion is 0.27. The total ATE in percentage terms (-18.2%) is the difference between the TL and BL entries, indicating that employed individuals are 18.2% less likely than unemployed individuals to walk with companions, or equivalently, that unemployed individuals are about 1.2 [100/(100-18.2)] times more likely to walk with companions than employed individuals. Next, proceeding to the exogenous variable effects on frequency, the first three sub-columns are similar to that for SC, and represent total effects of the variable. Thus, the entry of “3.58” for employment status under the “BL” column indicates that unemployed individuals walk, on average, 3.58 days in a week, while employed individuals walk, on average, 3.73 days in the week (with a corresponding total ATE change of 4.2%). The next main column labeled “% contribution by source of effect” under “Frequency” splits the total employment effect into percentage effects mediated through an SC effect (-34.5%) and a direct effect (+65.5%). Note that the sign associated with the percentage contribution is used to illustrate whether the effect decreases the total ATE (-) or increases it (+), while the relative magnitudes of the effects are computed to total 100%. That is, as discussed in Section 4.1, employment reduces SC propensity, which through the positive SC effect on frequency, leads to a reduction in frequency (as represented by the -34.5% entry). But employment status also has a direct positive weekly frequency effect (as reflected in the +65.5% entry). Finally, for the exogenous variable effects on duration, the layout is similar, except that the total effect is now partitioned into an indirect SC effect, an indirect frequency effect, and a direct effect. Thus, employment has a total ATE effect of -6% on walk duration per day, partitioned into a negative 82.1% contribution through the SC effect and a positive 17.9% contribution through the frequency effect.

Following the interpretive reasoning discussed above, we are able to make several observations related to the effects of the exogenous variables on walking dimensions that cannot be inferred from the estimation results. First, the ATE analysis allows us to compare the true and total magnitude of influence of exogenous variables on the three walking measures. For example, contrary to what the coefficients suggest (0.143 for women versus 0.204 for children), gender has a stronger overall negative effect on walking frequency than living with children. This is because households with children tend to have a higher propensity for walking companions, which partially offsets the direct negative effect through a positive indirect effect (+37.1%) mediated by companionship. Similarly, the effect of employment is weaker than high-income status due to the lower tendency of employed individuals to walk with companions. Second, the ATE analysis identifies the indirect effects of variables on the three outcomes, even in the absence of any direct effects. For example, living alone significantly reduces walking frequency and duration (ATE of -7.4% for frequency and -15.4%, respectively) due to the negative indirect effect of SC. Black individuals also walk less frequently and for shorter durations, not directly because of their racial and cultural background, but indirectly through low SC. Third, this approach allows for decomposing the contribution of each pathway from exogenous variables to outcome variables. The effect of child presence on walking illustrates this nuanced interplay. It includes (1) a positive indirect effect mediated through SC (+46.6%), (2) a negative indirect effect through frequency (-10.1%), and (3) a direct negative effect (-43.3%). This decomposition shows that the positive effect of having a child through higher SC is close to more than canceled out by the negative indirect effect through frequency and the direct negative effect, especially in households with three or more adults, resulting in shorter walk durations for these households compared to two-adult households without child. Overall, these effects balance out, resulting in a minimal total ATE of -2.1%.

Finally, toward the end of the table, we also compute the ATE effects of the endogenous outcomes, even though they are not exogenous variables. While these effects are implicit in the pathway effects for the exogenous variables, they provide valuable insights for policy development. For these calculations, we consider a change from the BL of "sometimes or less" to the TL "often or always" for the SC outcome, and from the BL of "less than 3 times a week" to the TL of "3 times a week or more" for walk frequency. These endogenous outcome effects reveal a substantial impact of SC on walking frequency (ATE of 96.1%). SC also influences walk duration with an ATE of 272.1%, with 82.9% of this effect coming directly from SC and 17.1% indirectly through its effect on frequency. Additionally, frequency itself affects duration with an ATE of 45.4%.

Table 6. Average Treatment Effects (ATEs)

Variables	Base Level (BL)	Treatment Level (TL)	Social Companionship (SC): Share of SC often/always		Social Companionship (SC): Total ATE (%)	Frequency: Waling Frequency (per week)		Frequency: Total ATE (%)	Frequency: % Contribution by sources of effect*		Duration: Walking Duration per day (Min)		Duration: Total ATE (%)	Duration: % Contribution by sources of effect*		
			BL	TL		BL	TL		SC	Direct	BL	TL		Freq.	SC	Direct
Individual Characteristics																
Age	50-64	65 or more	0.30	0.30	0.0	3.77	3.50	-7.2	0.0	-100.0	46.12	39.22	-15.0	-8.2	0.0	-91.8
Gender	Man	Woman	0.30	0.30	0.0	3.82	3.47	-9.2	0.0	-100.0	46.75	39.09	-16.4	-11.1	0.0	-88.9
Race	Non-black	black	0.31	0.26	-16.1	3.69	3.52	-4.6	-100.0	0.0	43.91	40.16	-8.5	0.0	-100.0	0.0
Employment status	Retired or not employed	Employed	0.33	0.27	-18.2	3.58	3.73	4.2	-34.5	+65.5	44.43	41.77	-6.0	+17.9	-82.1	0.0
Household Characteristics																
Household composition	Two adults without child	Single adult without child	0.31	0.22	-29.0	3.77	3.49	-7.4	-100.0	0.0	44.74	37.87	-15.4	0.0	-100.0	0.0
		Single/Two adults with a child	0.31	0.40	29.0	3.77	3.57	-5.3	+37.1	-62.9	44.74	43.82	-2.1	-10.1	+46.6	-43.3
		Three or more adults without child	0.31	0.31	0.0	3.77	3.77	0.0	0.0	0.0	44.74	39.73	-11.2	0.0	0.0	-100.0
		Three or more adults with child	0.31	0.40	29.0	3.77	3.57	-5.3	+37.1	-62.9	44.74	41.58	-7.1	-8.7	+39.9	-51.4
Household income	$100,000 or more	<$100,000	0.30	0.30	0.0	3.82	3.60	-5.8	0.0	-100.0	48.46	41.25	-14.9	-7.9	0.0	-92.1
Endogenous Variables																
Social companionship (SC)	Sometimes or less	Often or Always	--	--	--	2.79	5.47	96.1	+100.0	0.0	23.98	89.24	272.1	+17.1	+82.9	0.0
Frequency	Less than 3 times a week	3 times a week or more	--	--	--	--	--	--	--	--	32.74	47.59	45.4	+100.0	0.0	0.0

* The percentage contribution of each pathway is determined by the origin of the effects. For example, the indirect effect of companionship on walking duration includes the influence of companionship on walking frequency, which then impacts duration, as well as the influence of companionship itself on duration. The absolute value represents the relative magnitude of the effect from each source, regardless of whether the effect is positive or negative.

6. POLICY IMPLICATIONS

Building on the ATE analysis findings, this section identifies approaches to promote walking through tailored initiatives focusing on social support, infrastructure improvements, and awareness/incentive programs.

6.1. Promoting Social Companionship in Walking

Social companionship dominates over all other demographic effects in promoting walking frequency and duration, as clearly observed from the total ATE effects in Table 6. This has not been lost on major health organizations, such as the American Heart Association and the British Heart Foundation, which recommend group walking as a beneficial and enjoyable way to promote physical activity (American Heart Association, 2024, and British Heart Foundation, 2024). However, until this study, there has been little quantification of this benefit, as we are able to do using our ATE analysis. Further, Table 6 reveals that specific groups do tend to walk less or more in groups; Black individuals, those employed, and single adults without children walk less in groups, while those in households with children walk more as a group. No significant difference is found in group walking behavior based on age and gender. Nudging individuals to walk in groups within any of the above population segments should be beneficial in addressing physical activity deficits and inequities, as we selectively discuss below.

Starting with age disparities, although there is no difference in the frequency of walking with companions between those aged 50-64 and seniors, the older group exhibits lower walking frequency and duration levels. For individuals aged 65 and over, significant barriers such as reduced mobility and safety concerns, particularly the fear of falling or getting hurt, can result in decreased walking. This initiates a negative snowballing cycle where lower walking levels diminish physical ability, that then leads to even less walking, which further continues the downward spiral (Freiberger et al., 2020). Group walking initiatives and buddy systems can help break this cycle, providing support, shared experiences, and guidance from group leaders on safe/accessible routes to alleviate fears and instill a sense of security. Having a regular walking partner also promotes accountability and motivation for an active lifestyle. Policymakers can encourage programs through partnerships with senior centers, parks/recreation departments, and healthcare providers. These partnerships can take the form of funding and logistical support for the formation of senior-focused walking groups led by trained facilitators to provide guidance on proper walking techniques, pacing, and safety measures.

Moving on to gender differences, women often face unique barriers to walking, such as feeling less safe walking alone, especially in certain areas or during certain times of the day, due to the risk of harassment or violence (see Rišová and Sládeková Madajová, 2020). Social companionship can act as a deterrent to potential harassers or attackers. Additionally, women are known to prioritize social interactions in general (see Van Uffelen et al., 2017), viewing social networking as a way to build personal relationships. This generic social tendency, however, does not seem to translate to group walking among women, but opens up an avenue to leverage such motivations. Existing online platforms such as Meetup, SweatPals, and Facebook groups can be employed to organize women-focused walking events at local parks, trails, and neighborhoods. Such platforms can also benefit other demographic groups, such as singles (for example, "Single's Hike" events on Meetup), who are 29.0% less likely to walk with companions based on the ATE analysis. Also, households with children, who exhibit a high propensity for walking with companions (ATE of 29.0%), can greatly benefit from group walking initiatives that facilitate bonding experiences across family/friend networks. Walking clubs that accommodate all ages, with flexible schedules and family-friendly routes, can particularly encourage multi-generational group walks.

Table 6 reveals that racial minorities, particularly Black individuals, experience lower walking frequency and duration, primarily due to their reduced likelihood of walking with companions. Meanwhile, compared to those from high-income groups, low-income individuals walk around 5.8% less frequently and for about 14.9% shorter durations, though there is no variation in social accompaniment between income groups. Regardless, interventions focusing on companionship can benefit Black and low-income populations; previous studies have demonstrated the important role that fostering social cohesion and social capital plays in dealing with, and cushioning, the repercussions of systemic inequalities in society, even beyond the physical health benefits of walking groups (see Rigby et al., 2020 for a comprehensive review of the relevant literature). Potential strategies include forming groups with shared backgrounds to create a sense of belonging, and supporting the development of community-based walking programs that are led by trusted local organizations, such as churches or cultural centers. This should be particularly effective for racial minorities, who have lower levels of generalized trust, trust in neighbors, and trust in community due to racism-related experiences (see Wilkes and Wu, 2019, and Evangelist, 2022).

6.2. Improving Infrastructure and the Built-Environment

Beyond the mediating effects of companionship, individual and household characteristics also directly influence walking frequency and duration, suggesting customized measures to address the walking barriers faced by different groups.

To improve the walking environment for seniors (aged 65 and older), age-friendly infrastructure investments should help. This includes ensuring sidewalks and walking paths are well-maintained, free of tripping hazards, and equipped with sufficient lighting and benches for resting. Seniors feel more comfortable and safe in parks that have places to sit, are flat, and are well-maintained (see Veitch et al., 2020). Collaborating with local transportation agencies to implement road "diet" programs in areas near senior centers, and providing ample time for seniors to cross streets safely, are additional avenues to promote walking. Furthermore, community efforts can be directed toward the design of walking trails and loops in parks/community spaces with gentle inclines, stable surfaces, and handrails, all of which can provide a secure, comfortable, and inviting walking environment for older adults.

The presence of children in households (regardless of the number of adults) has a direct negative impact on walking intensity (both in terms of frequency and duration), presumably due to childcare-related time constraints, but also has a mediating positive impact through increased group walking. To leverage the positive inclination for group walking in such households, neighborhood walkability, particularly around schools, can be improved. Such interventions can take the form of traffic calming measures around school zones to discourage through traffic, installing high-visibility crosswalks and lighting, and the strict enforcement of speeding laws (see Rothman et al., 2022). These measures can lead to increased walking of caregivers to school with their children/grandchildren, while also bringing the benefits of multi-generational companionship. In this context, some studies suggest that pedestrian-related crashes in and around schools are because parents' inadequate education of their children on safe walking (see Cloutier et al., 2021), as well as their parking habits during pick-up and drop-off , such as double-park or block bus stops, which can result in students being in the street and obstructing sights of drivers, and dropping children at the opposite side of the road from schools that can cause uncontrolled, dangerous crossing (see Abd El-Shafy et al., 2017 and Rothman et al., 2017 for observation results). Adult traffic safety training classes conducted through parent teacher associations (PTAs) can be helpful in reducing such unsafe driving and walking practices. Another approach would be to work through schools to promote active living among students in middle and high schools, which then can increase walking among older adults in the household through social companionship effects.

Socioeconomic status (SES), including income and race, also emerges as a significant factor influencing walking habits, with lower-income individuals and racial minorities often facing physical barriers to safe and accessible walking infrastructure. For example, while there are many considerations related to the walking environment in SES neighborhoods, Haddad et al. (2023) observed that high transit use (typical in SES neighborhoods), combined with the traditional bus stop placement in close proximity of intersection crosswalks, contribute substantially to pedestrian crashes. This traditional stop placement serves to reduce the walking distance from across the street to a bus stop. But it also reduces the field of vision of a crossing pedestrian and also lowers the ability of bus drivers to spot crossing pedestrians (especially when making left turns; Samerei et al., 2021) Focused bus driver training programs, particularly for drivers traveling routes through neighborhoods with a high share of transit users and pedestrian movement, can help improve traffic safety at transit-embarking and transit-disembarking points. Other investments to promote walking in SES neighborhoods can include providing adequate lighting, benches, and green spaces. Richardson et al. (2020) reported an increase in walking within parks when such safety investments were made in the immediate proximity of SES neighborhoods.

6.3. Awareness/Incentive Programs

Raising awareness of the physical and mental health benefits of regular walking can be another useful strategy for promoting active lifestyles among seniors. Impactful education campaigns through both traditional media channels (television and radio) and digital social media can be effective, as adults over 50 spend a good part of their awake time watching TV and spend a comparable amount of time on social media relative to their younger peers (see Sheldon et al., 2021). Similarly, culturally relevant campaigns spearheaded by influencers from underserved communities can effectively communicate the availability of safe, accessible walking environments, while providing practical tips and strategies tailored to the specific needs and concerns of each target audience.

Awareness campaigns can also be complemented with approaches that leverage wearable activity- and fitness-tracking devices. Although their long-term impact on user behavior is still being studied (as reported by Heidel and Hagist, 2020), these devices show promise. Services based on activity tracking can boost walking among older adults in three ways. First, older adults can share and compare walking records virtually, such as daily step counts as collected by tracking devices. This can create a sense of community and accountability (see Foster et al., 2010, and Liu and Lachman, 2021), even if only virtually, particularly for those facing barriers to group activities. Second, most wearable devices are equipped with heart rate and blood oxygen sensors that can monitor vital signs. In case of emergencies, these devices can alert emergency services, providing immediate assistance if the wearer is injured or immobilized after a fall. This feature helps alleviate safety concerns that might otherwise discourage older adults from outdoor walking. Third, smartphone applications paired with wearable devices offer users the chance to set up and engage in weekly challenges and competitions, earning badges and rewards upon completion. This feature can boost motivation and accountability, encouraging users to maintain their physical activity levels, including walking. Also, several health insurance providers currently offer discounts on premiums for meeting physical activity goals. For instance, some insurance companies provide policyholders with up to $100 annually for achieving daily step targets when syncing a step tracker with their mobile application (see Bengfort, 2023). Similarly, partnerships with local or online businesses (such as sports stores) to offer rewards to individuals who meet a certain number of daily steps or who visit scenic outdoor sites (Kim et al., 2024) can serve as a tangible motivator for older adults. However, also to note is that only a quarter of seniors in the U.S. are estimated to wear fitness devices (Morning Consult, 2023). Implementing programs and services that offer educational resources and the opportunity to rent or borrow devices can further encourage their use among older adults. Additionally, manufacturers of activity-tracking devices should consider the needs of older adults, such as ensuring that the display screens are large and well-lit for easy readability.

Another emerging technology with the potential to improve walking habits among older adults is Intelligent Conversational voice assistants (ICVs), such as Siri on the iPhone. These ICVs provide real-time, voice-activated support, making them particularly beneficial for older adults who may be less familiar with technology or face challenges in navigating screen-based interfaces (see Bokolo Jnr, 2024). ICVs can promote walking through two primary functions. First, ICVs can assist users in finding and navigating safe and walkable routes, thereby reducing the fear of getting lost or concerns about route safety. Second, ICVs can serve as an accessible alternative to individualized professional coaching, which has been shown to positively impact physical activity participation (see Oliveira et al., 2017). As AI technology advances, the chasm between human coaching and ICV support may narrow, making ICVs an increasingly valuable and reliable tool to promote walking among older adults (see, for example, Mohan et al., 2020, and Vardhan et al., 2022).

7. CONCLUSIONS

This study has investigated the determinants of three separate, but inter-related dimensions of older adults' walking behavior: frequency of days of walk in the week, typical duration of walk during days of walk, and social companionship (SC). The analysis is undertaken using a multivariate mixed data approach (including two ordered-response outcomes and a grouped outcome), nationally representative survey data collected after the peak of the COVID-19 pandemic in July 2022. This approach facilitated the comprehensive understanding of the long-term effects of the pandemic on older adults' walking behaviors.

This study aimed to identify the relationships between sociodemographic factors and the three dimensions of walking behavior (frequency, duration, SC) among older adults, as well as capture the causal effects among these dimensions. Overall, the findings revealed significant, yet distinct, relationships between sociodemographic factors and each dimension of walking behavior. In terms of causal relationships, the presence of companions had a positive endogenous effect on both the frequency and duration of walking. Also, frequent walking positively influenced the average walking duration. Further, an average treatment effects (ATEs) analysis was conducted to quantify the overall impact of exogenous variables and decompose these impacts into direct and indirect effects mediated through the endogenous walking behavior variables (frequency and companionship). The findings suggested that older adults with fewer resources, such as those who are over 64 years, unemployed, from low-income households, and members of households with children, tended to walk less frequently and for shorter durations. However, the causal effect of SC revealed that certain groups, such as Black individuals and those living alone, walked less due to the absence of walking companions. These results highlight the importance of considering social aspects in understanding walking behavior and suggest that approaches to encourage walking need to be tailored to different social groups. By tailoring interventions to the unique needs of different populations and leveraging the power of community, companionship, and emerging technologies, policymakers can effectively foster a culture of active living among older adults and equitable access to the numerous benefits of regular walking.

The research in this study may be advanced in many ways. First, although we acknowledge the significant impact of the built and natural environment on walking, we could not explore this aspect due to the lack of data on respondents' residential locations. Future research should prioritize examining how these factors specifically affect older adults' walking behavior, especially since this demographic may be particularly sensitive to environmental conditions due to factors such as fear of falling, concerns about safety, and vulnerability to weather conditions (see, for example, Li et al., 2015). Second, our study highlighted specific sociodemographic groups that may benefit from interventions that promote walking. To better inform the design of such interventions among older adults, it would be beneficial to collect subjective perceptions on the barriers and concerns that influence walking behaviors. Third, since utilitarian and leisure walking trips have distinct characteristics, analyzing them as separate behaviors would provide deeper insights.

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