ASSOCIATION BETWEEN GAIT SPEED AND RESIDENTIAL ENVIRONMENT AMONGST OLDER ADULTS

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ABSTRACT

The ability to help mitigate prevalence of disability in the aging population may be developed by expanding the list of known risk factors to include environmental exposures. Understanding environmental risk factors for health is of public health importance. We contribute to these efforts by asking: Are attributes of the social and built residential environment able to explain between-people differences in gait speed? A cross-sectional analysis of relatively healthy community-dwelling older adults was conducted using baseline participants (n=2,637; female=52%; average age=74±2.89; Black=39%) from the Health, Aging and Body Composition (Health ABC) Study. Performed 6 meter walk at usual gait speed was the outcome of interest. The associations between measures of the residential environment (tracts) and gait speed (meters per-second, m/sec) were assessed using linear regressions. After adjusting for socioeconomics, health behaviors and conditions, results indicated that neither street connectivity nor net residential density explained between-people variance in gait speed. Poverty concentration did explain between-people variance in gait speed. Living in a tract where a 30% or more of the residents are in-poverty is associated with a 0.02 m/sec slower gait speed when compared to living in a tract where poverty concentration is ≤9%. In this observational study, poverty concentration in residential environment was significantly associated with gait speed. Research should continue to explore if and how aspects of the residential environment may explain physical function differences among older adults.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Even though reaching older ages is not always accompanied by impaired lower extremity mobility [Lunney 2003]; gait abnormalities (e.g., slow walking) do tend to become prevalent at older ages [Rosso 2013; Siordia 2014a]. For example, information on about 1.5 million community-dwelling older adults (aged > 65) in the United States (US) indicates difficulty with walking can be found in about 25% of Non-Latino-Whites and 35% of Non-Latino-Blacks [Siordia 2014b]. Because evidence abounds that prevalence of disability varies by class, race, and sex [Siordia 2014c], a common perspective in public health is that gait abnormalities are not randomly distributed—and are thus eligible for intervention. Because interventions may be more effective if conditions leading to adverse health are detected in pre-symptomatic stages, understanding sequelae of morbidity requires delineating antecedents of disability. Our study examined environmental risk factors for subclinical disability to help identify novel risk factors for subclinical gait abnormalities.

We begin our discussion by briefly introducing ideas from medical geography and then explain why measures of the social, physical, and built environment matter for aging research on ambulation. Because gait speed has been argued to be a useful single-item assessment tool in both healthy & frail adults and in both research and clinical settings [Cesari 2005], we investigated the relationship between measures of the social and built residential environment and gait speed. We argue environmental exposures reflect where individual resources place a person within their socio-ecosystem. This is important because environmental markers of social stratification processes may be determinants of health [Marmot 2005]. Our position is that geographical location is a product of social processes and capable of aggravating or reinforcing dis/advantages for health. Our search for environmental risk factors for gait abnormalities may help inform efforts aimed at mitigating ambulatory disability at older ages. After describing data sources and methods, we discuss our findings and provide a brief conclusion with suggestions for future research.

1.1 GEOGRAPHY OF DISEASE

The mapping of health information has been in practice for centuries. For example, in the early 1790s, Seaman mapped a yellow fever outbreak in New York City [Seaman 1796]. In the 1810s, the mapping of cholera cases, within garrisons of British soldiers in India, helped understand the origin of the contagion [Jameson 1819]. As evident by the more recognized work of John Snow, a founder of epidemiology, a geographically aware perspective is crucial for advancing public health [Snow 1849]. It was only after Snow mapped the geographical distribution of cases that he was able to detect the most important risk factor for cholera: the water pump at Broad Street [Newson 2006].

No amount of information on the individual would have identified the Broad Street pump without the basic element of geographical location—a measure that required geocoding cholera cases. Geocoding refers to the process of assigning geographic location to study observations. To geocode is to geographically reference data in the production of environmental measures. In our study, we geocoded cases to assess how attributes of the residential environment help explain between-people variance in gait speed.

1.2 ENVIRONMENT AND DISEASE

The environment has featured in models of disease causation for centuries. For example, in the 1930s, Selye argued under the General Adaptation Syndrome that chronic stress from environmental exposures could shorten the lifespan [Selye 1976]. In the 1970s, Cassel eloquently spoke about the contributions of the environment to weakening host resistance [Cassel 1976]. In the 1980s, the Glucocorticoid Cascade Hypothesis was proposed—the possibility that consistent downregulation of glucocorticoid receptors from stressful environments precipitated permanent hippocampal cell loss [Sapolsky 1986]. In the 1990s, the concept of 'allostatic load' was presented to explain how overexposure to hostile environments may produce imbalance in physiological systems aimed at promoting homeostasis [McEwen 1998].

In the early 2000s, the Accelerated Aging hypothesis linked environmental stimuli with causal mechanisms of disease in the aging process [Berkman 2000]. By the mid-2000s, the "Weathering" hypothesis was presented to argue that environmental factors could impact multiple systems in a subclinical way and over the life-course to increase risk for morbidity [Geronimus 2006]. In the late 2000s, the Glucocorticoid Vulnerability Hypothesis helped explain how conditions, partially affected by environmental stimuli, produce dendritic retraction to make the hippocampus vulnerable to metabolic and/or metabolic challenges [Conrad 2008]. More recently, research has explained how physical and social environments might affect activity of the human genome to acerbate the progression of adverse health [Cole 2014]. As evident by models of disease causation over the decades, factors in environment may play a key role in the etiology of pathology in aging processes.

1.3 ENVIRONMENT AND DISABILITY

We began our study under the empirically informed view that environmental exposures may play a key role in how humans are able to obtain and retain the ability to walk. Because difficulty with walking is prevalent at older ages, public health has sought to identify risk factors for abnormal gait. Intervening on risk factors may help ensure added years from increased life-expectancy and medical intervention are spend free of disability. Epidemiology, a discipline concerned with identifying risk factors for disease in the population, works towards contributing to efforts aimed at mitigating prevalence and severity of disability. Within epidemiology, aging research in the US focuses on the population aged 65 and over. Aging research is currently limited in that it primarily focuses on identifying person characteristics as risk factors. Our study advances aging research by focusing on environmental attributes as risk factors for abnormal gait speed.

Because where we live may matter for health, the socio-medical framework on disablement processes describes environmental factors as capable of intervening on the progression from physical vitality to disability [Nagi 1976; Verbrugge 1994]. Work has argued the essential role of the environment in the aging process [Lawton 1973] and continues as spatial epidemiology grows [Osfeld 2005]. Evidence exists that attributes in physical and social environments help explain physical mobility [Rosso 2011]. Figure 1 presents our conceptual model. Our approach posits the environment plays a key role in all stages of disabling processes throughout the life-course. Our model highlights how stages in the progression towards gait abnormalities are nested within intra-individuals factors and over the environment throughout the life-course.

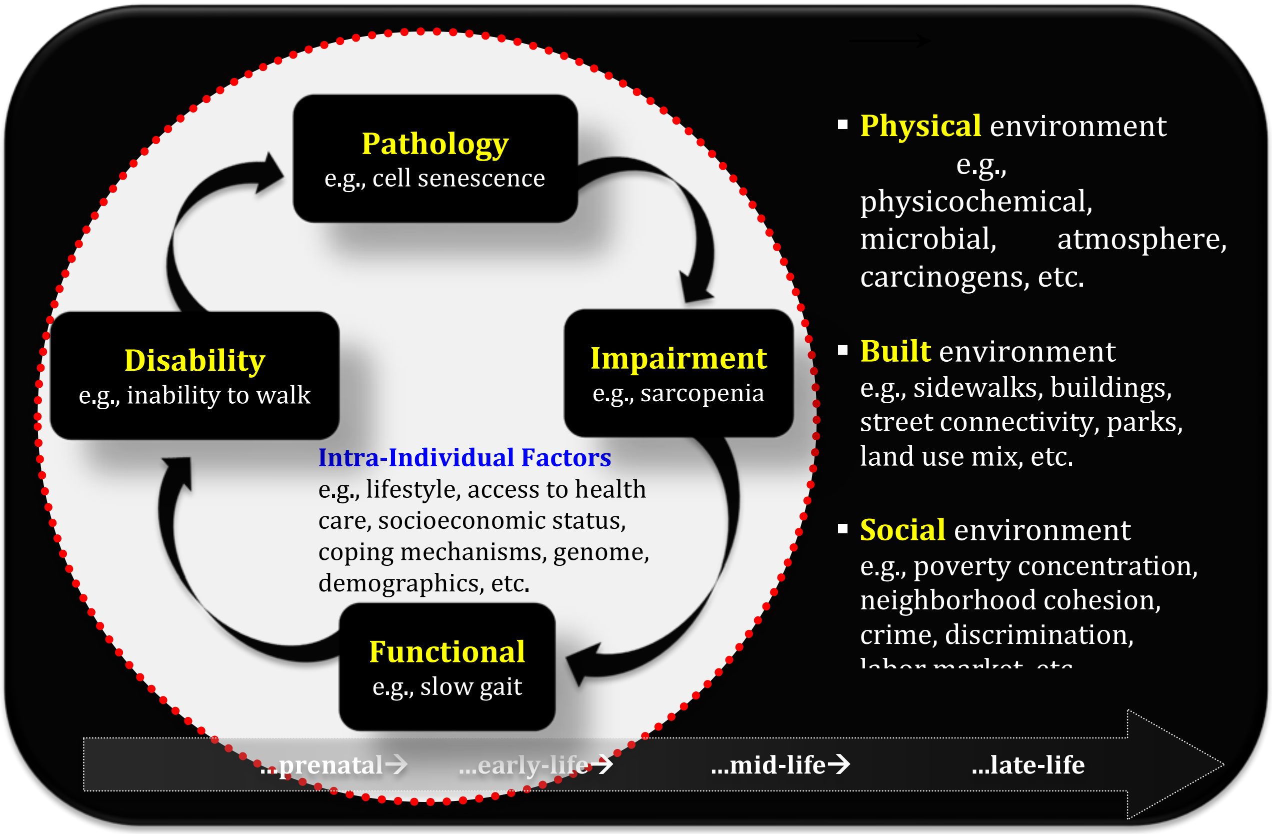

Figure 1. Conceptual model of how environment affects stages in disabling processes

1.4 ATTRIBUTES OF ENVIRONMENT AS RISK FACTORS

Why should researchers in aging be concerned with identifying environmental attributes as risk factors for abnormal gait? Evidence abounds that habitats have the ability to influence health. Why not ask person-anchored questions about the environment? As with Snow's water pump, there are attributes of the habitat that may never be captured by measures of the individual. As the geocoding of cholera showed, assigning attributes of the environment to cases (i.e., distance from water pump) helped identified the geographical pattern used to ascertain the main risk factor.

The characteristics of the environments we inhabit speak of our individual achievements, preferences, resources, and limitations. As shown in Figure 1, environments contain exogenous elements capable of affecting our health. The characteristics of the physical spaces we inhabit capture how our decisions have interacted (over time) with social arrangements to determine our place of residence. Measures of the environment are more than the sum of person characteristics: they capture how individual resources have been taxed and replenish by resource-filled or –depleted habitats. Researchers in aging should aim to identify environmental attributes as "social determinants" (i.e., risk factors) for abnormal gait because they have the capacity to measure the effects of *social arrangements* on health.

At the core of "health and place" research is the testable hypothesis that some disablement processes are malleable and the product of bi-directional interactions between intra- and inter-personal forces [Freedman 2008]. For example, gait speed may vary as a function of person characteristics over time (P_t), attributes of the environment over time (E_t), their interaction over time (PE_t), and random events over time (R_t):

$$Gait\ Speed = \int (P_t, E_t, PE_t, R_t)$$

Most epidemiological investigation focus on identifying risk factors associated with P_t. Because epidemiologist are most concerned with identifying risk factors for disease, their health and place research has sought to isolate the independent contribution of E_t for adverse health [Cummins 2007].

Isolating the effect of E_t on adverse health has been argued to represent a false dualism between person and place. The "relational" view aims at eradicating false dualisms between person and place. The relational framework posits a mutually reinforcing and reciprocal relationship exists between people and environment [Cummins 2007]. For example, gait deterioration may be exacerbated by a hostile environment where walking is made dangerous by fall-prone surfaces. From the relational view, gait disturbances and dangerous surfaces reciprocate over time to speed up the disablement process. Isolating the risk for abnormal gait development in walking surfaces ignores the fact that any meaning assigned to surfaces is partially influenced by the capacities of the individual. For instance, a fracture on the cement-sidewalk that creates a ½ inch elevation on the surface would only be hostile to someone with spastic gait (foot-dragging) and inconsequential to others. We use the relational perspective in our discussion of results to highlight PE_t. Note our study does not include the element of time.

1.5 ENVIRONMENT AND CUMULATIVE DIS/ADVANTAGE

Our cross-sectional and exploratory analysis adds to the literature by answering the following research question: Do attributes in the residential environment help explain between-people differences in gait speed? Although we ultimately identify which attributes of the residential environment are risk factors for abnormal gait speed, our discussion is framed from the relational view. We discuss environmental exposures as contributing towards cumulative dis/advantage in older adults [Crystal 1990]. Discussing the statistical relationship between gait speed and residential environment in terms of cumulative dis/advantage highlights that while the independent risk associated with the environment may be small, it contributes towards helping understand between-people differences in gait speed.

Cumulative dis/advantage is the product "of institutional arrangements and aggregated individual actions over time" [Angela 1996]. Attributes of the environment represent how interactions between individuals' agency and their inhabited social structures culminated to produce net economic and health dis/advantage [Braveman 2006]. The non-random allocation of populations over health-heterogeneous geographies captures how temporally sensitive geospatial distributions contribute to cumulative health dis/advantage—*above and beyond person characteristics* [Kaspar 2015]. Fortunately for public health, the non-random distribution of populations over risk-diverse geographical locations implies that between-population differences in health may be mitigated.

In aging research, environmental markers of social stratification processes are frequently ignored determinants of health. Measuring economic disadvantage at the person level, through personal income or educational attainment, ignores a portion of the full picture. Accounting for economic disadvantage in the environment is equally important. For example, living in-poverty may be further aggravated by residing in a neighborhood that has historically experienced deep poverty. Poverty in a historically low-resource environment may be a greater risk for morbidity than living in-poverty within a resource-rich environment. The main point is that environmental markers of social stratification processes may be notable determinants of gait abnormalities.

The importance of social processes in geospatial arrangements is ignored in research that omits measures of place. This is detrimental because non-geographically aware research implicitly assumes aspects of the environment are inconsequential for health or similar for all participants. That is, not accounting for attributes of habitat is paramount to assuming that study participants are all exposed to the same environment—an improbable assumption for most observational studies in aging. Including measures of the environment provides a more realistic representation of conditions affecting health. By interpreting statistical relationships between gait speed and measures of the residential environment through a cumulative dis/advantage framework, we position PE_t at the forefront of our discussion. Framing the assessment of risk factors for abnormal gait through a geographically-aware perspective may help public health.

1.6 PHYSICAL FUNCTION AND ENVIROMENT

Researchers in aging have investigated associations between environmental exposures and physical function. The main hypothesis motivating this line of research is that attributes of the environment may be capable of speeding up or slowing down the progression from pathology, to impairment, functional limitation, and then disability. Studies that included individuals aged $\geq$ 65 have investigated an array of subjectively and objectively assessed physical function related outcomes while *subjectively* assessing the environment [Shumway-Cook—Becerra]. These studies showed negative environmental attributes are associated with more incident loss of function, higher level of impairment, more activity limitation, and worse disability trajectories. Other researchers have investigated subjective and objective measures of physical function while *objectively* measuring the environment with samples that included adults aged $\geq$ 65 [Clarke—Beard]. These studies found low-resource environments were associated with more incident impairment, higher level of difficulty with activities of daily living, worse outdoor mobility disability, smaller life space, and lower transport walking.

Empirical findings provide support to arguments that aspects of the environment help explain between- and within-people variance in physical function [Yen 2009]. Our study is novel because it used objective measures of the residential environment to help explain observed physical function (i.e., gait speed). Understanding how cellular processes contribute to organ deterioration in the production of the functional impairments that culminate to produce disability, necessitates environmental markers of social stratification be considered. Under the literature-informed view that genes, biology, random events, and the environment affect health, we postulated that attributes in individuals' habitat would help identify non-random mechanisms affecting gait speed.

2.0 METHODS

The analysis used a total of 2,637 study participants from the Health, Aging and Body Composition (Health ABC) Study, an ongoing observational prospective study on the relationship between body composition and mobility disability. Study participants were sampled from a list provided by the Health Care Financing Administration (HCFA) from zip code areas comprising Shelby County in Tennessee and Allegheny County, Pennsylvania. All African Americans in the HCFA list, a replicate sampling fraction of white individuals in the HCFA list, and all age-eligible household members were asked to participate in the study. For African-Americans, additional lists were used: including Veteran's Administration records.

To be eligible to participate at baseline, individuals had to be between the ages of 70 and 79 at the time of recruitment and self-reporting having no difficulty with activities of daily living (defined as self-reported difficulty walking ¼ mile or climbing a flight of 10 steps without resting). Individuals were excluded for multiple reasons including participation in a lifestyle intervention trial, having recent treatment for cancer, or intention to move out of the study location within 3 years of study start date. Baseline examinations took place between April 1997 and June 1998. The study was in accordance with the ethical standards of the IRBs of participating intuitions: the University of Pittsburgh; the University of Tennessee; and the coordinating center at the University of California San Francisco. Trained interviewers obtained consent from each HABC Study participant, administered surveys (where they obtained participants' home address), and examinations.

2.1 GEOCODING

Because the US Census Bureau does not provide single address-to-address Topologically Integrated Geographic Encoding and Referencing Line (TIGER/Line®) shapefiles, Health ABC addresses were geographically referenced to "potential address ranges" by using a "US address—dual ranges" locator. Health ABC participants were assigned an X- and Y-coordinate by using their place of residence. This was achieved by using address locator algorithms in ArcMap® 10.1 software—a popular Geographic Information System (GIS) platform. Latitude and longitude coordinates were used to identify a participant's US Census Bureau year-2000 block. Geocoded addresses where spatially joined with the block using ArcMap® 10.1 and requiring that the geometric centroid of the geodetic point fall within the block. All shapefiles were projected using the USA Contiguous Albers Equal Area Conic on the North American Datum of 1983. The projection helps preserve geographical area.

A "block" is the smallest administrative spatial unit used by US federal government agencies for reporting public data. The geographical boundaries of blocks are formed by visible (e.g., streets) and invisible (e.g., school district boundaries) features. Although Health ABC participants were geocoded to the block-level, we produce measures of the residential environment at the tract-level in order to measure poverty. Because US Census "tracts" are the smallest unit used to disseminate socioeconomic measures of the population, we used the block identification number (15 digits) to geographically reference individuals to their "residential area" (i.e., year 2000 tract of residence).

Tracts are administrative spatial units built from blocks and are drawn as-per administrative needs. Tract geographical boundaries are not influenced by either social theory or people-defined borders of meaningful neighborhoods. Tracts range in population from about 1,200 to 8,000 people. Tracts usually cover contiguous areas but may be made up of multi-part polygons [Siordia 2013]. In heavily populated areas, tracts can be less than a square mile and in low-populated regions be made up of hundreds of square miles. In our study, the average tract size was 1.4 square miles (mi2).

Geocoding was done to year 2000, which represents a 2 to 3 year time-lag between outcome and environment assessment. Of the 3,075 enrolled in the Health ABC Study at baseline, 1,396 (90% of 1,548) in Shelby County and 1,303 (85% of 1,527) in Allegheny County were geocoded. From those geocoded, 96% (n=1,340) in Shelby County and 99% (n=1,297) in Allegheny County had complete data on all the variables of interest. Because of our selectivity, caution should be used in generalizing our findings beyond the analyzed sample of 2,637 individuals.

2.2 GAIT SPEED

Gait speed from baseline clinic assessment, our main outcome, was measured at usual pace from a standing start over 6 meters and expressed as meters per-second (m/sec) to allow for inter-study comparison of different distances [Simonsick 2001]. In observational studies, usual gait speed is frequently used because it is quick, safe, inexpensive, and highly reliable [Peel

2013]. The faster of the two trials was used and gait speed was modeled as a continuous outcome. We provide a graph of slow and fast walkers stratified by poverty concentration in residential area. A task force recommended treating gait speed > 1.0 as normal and gait speed > 1.4 as superior [Studenski 2009]. In our study, we observed the prevalence of "slow walkers" (< 1.00 m/sec) and "fast walkers" (> 1.4 m/sec) by poverty concentration.

2.3 POVERTY CONCENTRATION IN RESIDENTIAL ENVIRONMENT

At the tract-level, we calculated the percent of people living in-poverty. This is measure of the social environment. Percent in-poverty was obtained from year-2000 US Census Bureau Summary File 3 (SF3). These files contain survey information on a sample of about 1 in every 6 households in the community-dwelling US population. Percent in-poverty represents the sample-derived estimate of individuals below the US Federal poverty threshold divided by the number of individuals for whom a poverty score is calculated in the tract.

We separated study participants into the following approximate quartile categories of residential poverty concentration: percent in-poverty < 9.99% (reference category); percent in-poverty between 10% and 19.99%; percent in-poverty between 20% and 29.99%; and percent in-poverty > 30%. From the 2,637 participants in the analysis, 28% resided in a low poverty area (<9%), 30% in a moderate-to-low poverty are (10%-19%), 18% in a moderate-to-high poverty area (20%-29%), and 24% amongst the high-poverty areas (>30%).

Approximate quartiles were used in order to follow existing approaches [Census 2014]. Because residential areas (tracts) with a high percent of people living in-poverty may be characterized as low-resource environments, we expected to find slower gait speeds for individuals in the last 3 categories when compared to those in low-poverty concentrated tracts (i.e., where percent in-poverty < 9.99%). In other words, we expected to find a negative relationship between gait speed and percent in-poverty in the residential area.

2.4 NET RESIDENTIAL DENSITY

Because estimates of poverty are only made available at the tract level, we accommodated two other measures of the residential environment to the tract geography. We measured the built environment by computing net residential density at the tract level. This is measure of the built environment. Net residential density is treated as a proxy measure of land use mix [Frank 2004]. Land use mix refers to areas having a diverse set of land uses: such as residential, shopping, and recreation spaces. Areas with diverse land use may induce participation with public transportation, outdoor walking, and cycling. In turn, engagement with outdoor activities may promote perceived security in place of residence for community members and ultimately better health.

Data for net residential density was obtained from year-2000 US Census Bureau Summary File 1 (SF1) and quantified at the tract level using ArcMap® 10.1. We divided the total number of housing units in the tract by the total area in square miles (mi2). Housing units refer to structures (e.g., houses and trailers) categorized as available for domestic occupancy. Net residential density equals the number of housing units per mi2 within residential tract.

A small number of housing units within tract would indicate a low level of land use diversity. In contrast, a large number of housing units within the tract suggest a beneficial level of land use diversity. Work has shown land use diversity promotes transport walking [Saelens

2003] and transit ridership [Frank 2000]. When compared to those residing in the quartile with the lowest net residential density, we expected to find faster gait speeds in the other quartiles. That is, we expected to find a positive association between gait speed and net residential density.

2.5 STREET CONNECTIVITY IN RESIDENTIAL AREA

We aggregated street connectivity to the tract level. This is measure of the built environment. Street connectivity was measured by using street intersections as identified in ArcMap® 10.1. Street centerline data from TIGER/Line® shapefiles were used to identify intersections where 2 or more unique streets connected. After we "unsplit" centerlines in ArcMap® 10.1 (to merge connected line features and remove pseudo-junctions), we dissolved intersections by X- and Y-coordinates to delete duplicates. We then counted the number of intersections.

The geometrical centroids of intersections where used in a spatial join to sum them by tract. Work has shown density of connectivity is associated with better physical function [Freedman 2008]. The basic idea is that intersections represent "route choices" for pedestrians. An increase in pedestrian route choices is hypothesized to incentivize outdoor physical activity, and the latter better health. Thus, we expected to find a positive association between gait speed and level of street connectivity in tract. When compared to those living in the quartile with the lowest street connectivity level, we expected to find faster gait speeds in the other quartiles with higher levels of street connectivity.

2.6 COVARIATES

Our analysis accounted for the following socioeconomic factors: age, sex, race, if person was married, if person resides in a household whose combined income is at or below $10,000 per-year, whether person had an 8th grade educational attainment or below, and if person reported food insecurity. We also account for health behaviors as follows: body mass index (BMI, kg/m2), self-reported physical activity, if person reports eating alone all or most of the time, tobacco smoking and alcohol drinking during lifetime. For physical activity, a metabolic equivalent value was assigned to reported activities to calculate number of kilocalories per-week (kcal/wk) per-kilogram of body weight spent on the activity [Visser 2002]. Physical activity measure was logged-transformed because it was positively skewed.

We adjusted for health conditions using reported diagnosis of diabetes, hypertension, stroke, asthma, self-rated nighttime insomnia and daytime sleepiness, if person reported feeling leg pain when walking, if person reporting having to stop to breath when walking, if person reported activities had slowed down in past 12 months because of poor health, if person reported having fallen all the way to the ground at least once in the past 12 months, if person reported having difficulty stooping or kneeling, mental ability assessed via the Modified Mini-Mental State Examination (3MS) scale [Teng 1987], depression symptomatology was adjusted with using the Center for Epidemiologic Studies-Depression (CES-D) scale [Radloff 1977].

2.7 STATISTICAL APPROACH

After investigating the data, we identified linear regression as the optimum modeling approach. Even though we found nesting individual observations by tract revealed ≤ 9% of between-people variance in gait speed was explained by between-tract characteristics, we discovered 58% of 344 tracts contained ≤ 5 observations—representing 18% of the 2,637 observations in the study. A total of 94 tracts (27% from 344) contained ≥ 10 observations—representing 67% of the 2,637. In multi-level models, person-level coefficients operated similarly to betas in non-nested models presented in this report. The assumption of independence between people, with regards to measurements of the environment, could be argued to be violated by not using non-nested models. Because the vast majority of tracts had fewer than 5 observations and because the sample way not be geospatially representative, we decided not to use multilevel modeling and opted for the most straightforward approach (i.e., non-nested modelling). We provide descriptive statistics for the sample under analysis and present the categorical distribution of gait speed stratified by level of poverty in the residential environment. We explored the association between gait speed and environment using four regression models: the first with no adjustments; the second adjusting for socioeconomic factors; the third adding health behavior measures; and the final model adding measures of health conditions. Data was managed and analyzed in both ArcGIS® 10.1 and SAS® 9.3.

3.0 RESULTS

Table 1 present descriptive statistics stratified by residential poverty. Compare to the average gait speed of 1.21 m/sec for those in areas where $\leq$9% of the population was in-poverty, the average gait speed for those in areas where $\geq$30% of the population was in-poverty was 1.15 m/sex. About 74% of those residing in areas where $\leq$9% of the population was in-poverty were white, while only 46% were white in areas where $\geq$30% of the population was in-poverty. A total of 24% of those residing in areas where $\leq$9% of the population was in-poverty had a BMI $\geq$30, while 28% of those in areas where $\geq$30% of the population was in-poverty had a BMI $\geq$30.

Although not shown in the tables, we found the tract's percent in-poverty and street connectivity had an unadjusted Pearson correlation coefficient of -0.22 ($p<0.01$). Tract's percent in-poverty and net residential density had an unadjusted Pearson correlation coefficient of 0.29 ($p<0.01$). Street connectivity and net residential density had an unadjusted Pearson correlation coefficient of -0.48 ($p<0.01$). No multicollinearity was found in the fully adjusted model (i.e., all variance inflation factors < 1.5).

Table 1. Characteristics of geocoded Health ABC participants (n=2, 637)

	Residential Poverty ≤ 9%	Residential Poverty 10%-19%	Residential Poverty 20%-29%	Residential Poverty ≥ 30%
	n=737	*n=788*	*n=487*	*n=625*
	Mean	Mean	Mean	Mean
Gait Speed (m/sec)	1.21	1.19	1.16	1.15
Age (yrs)	74	73	73	74
Educational attainment	14	13	13	12
Physical activity (logged kcal/wk)	-0.12	-0.19	-0.27	-0.20
Emotional status (CES-D)	4	5	5	5
Cognition (3MS)	91	91	89	90
	%	%	%	%
Female	47%	52%	54%	55%
White	74%	64%	54%	46%
Married	56%	53%	47%	48%
Body Mass Index				
≤18.4	1%	2%	1%	1%
18.5 to 24.9	31%	29%	32%	30%
25 to 26.9	20%	19%	18%	19%
27 to 29.9	24%	24%	24%	31%
≥30	24%	25%	25%	28%
Tobacco Smoking				
Never	46%	42%	44%	46%
Former	47%	48%	47%	42%
Current	8%	10%	9%	12%
Alcohol Drinking				
Never	28%	27%	29%	28%
Former	18%	21%	23%	25%
Current	53%	52%	29%	45%
Diabetes	13%	15%	16%	17%
Hypertension	48%	52%	51%	51%
Stroke	2%	1%	2%	4%
Asthma	8%	9%	8%	7%
Arthritis	53%	55%	57%	57%
Activity slowed in past 12 months	14%	14%	20%	19%
Has fallen in past 12 months	24%	21%	19%	22%
Has difficulty stooping or kneeling	36%	37%	40%	36%
Feels leg pain when walking	17%	19%	23%	24%

3.1 GAIT SPEED BY POVERTY CONCENTRATION

Figure 1 displays the distribution of gait speed categories by concentration of poverty in the residential environment. Although we computed the distribution of gait speed categories for each group stratified by poverty concentration in the environment, we only present the prevalence of slow and fast walkers to highlight the main pattern. Comparing the slowest walkers (red bars) to the fastest walkers (gray bars) highlights what we expected: slower gait speeds are most concentrated in disadvantaged environments. Comparing those with a gait speed < 1.00 (slow walkers) to those with a gait speed > 1.4 (fast walkers) by poverty concentration in the environment reveals a clear pattern: high-poverty concentration areas are most represented by slow walkers, while low-poverty concentration areas are most represented by fast walkers. This geospatial pattern implies gait abnormalities are non-randomly distributed over geography

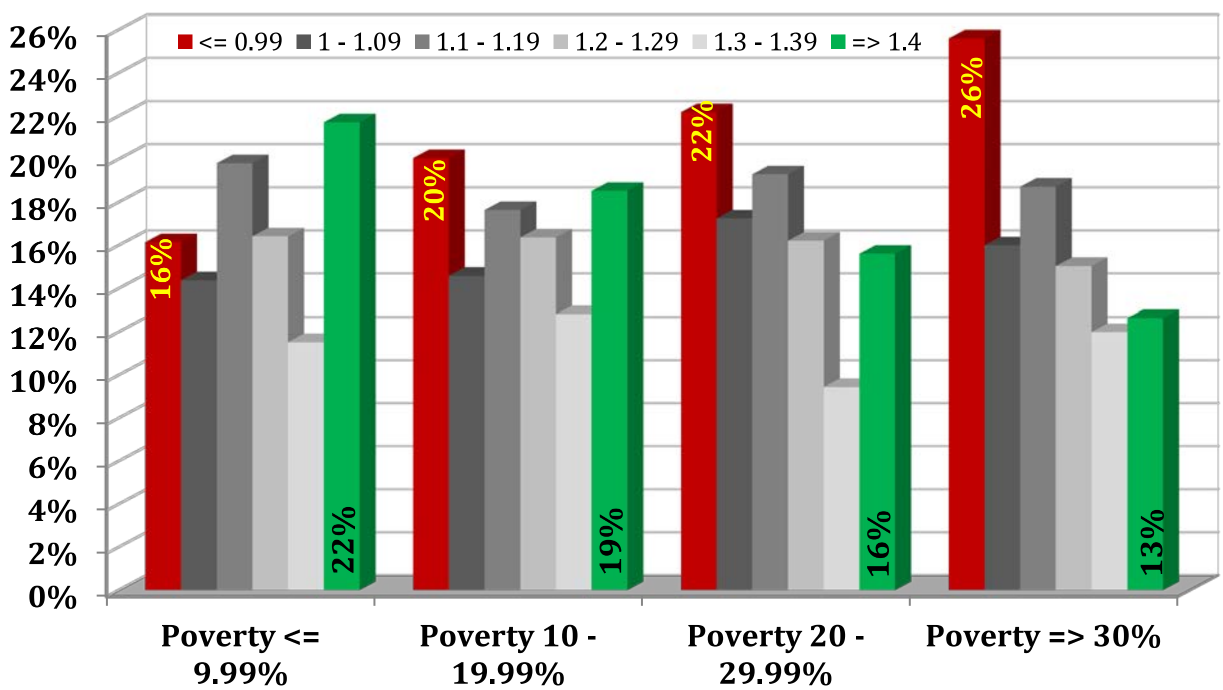

Figure 2. Fast and slow walkers by level of poverty in residential area

3.2 REGRESSION RESULTS

Table 2 presents the univariate linear relationship between gait speed and measures of the residential environment. As shown in Table 2, all the categories in level of poverty in the tract are related in a statistically significant way with gait speed. Model-4 in Table 3 indicates level of poverty remains associated with gait speed even after adjusting for the two measures of the built environment.

Table 2. Univariate relationship between environmental exposures and gait speed

	Model-1		Model-2		Model-3
Level of Poverty					
$\leq$9%	Ref				
10%-19%	-0.02	*			
20%-29%	-0.05	***			
$\geq$ 30%	-0.07	***			
Street Connectivity					
Low (Q1)			Ref		
Below average (Q2)			0.01		
Above average (Q3)			-0.03	*	
High (Q4)			0.01		
Net Residential Density					
Low (Q1)					Ref
Below average (Q2)					-0.02
Above average (Q3)					0.00
High (Q4)					0.01

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Model-5 in Table 3 shows that after full adjustment and when compared to those who resided in areas where poverty concentration is at or below 9%, residing in an area where 30% of people or more lived in-poverty was associated with 0.02 m/sec *slower* gait speed. Model-5 also indicates age, sex, race, and educational attainment helped explained between-people variance in gait speed. In terms of cumulative disadvantage and through the relational perspective, the fully adjusted model suggests that while holding all else constant, a black female residing in an area where 30% of people or more live in-poverty is at risk of walking 0.22 m/sec *slower* than a white male residing in an area where 9% of people are living in-poverty. That is, when combined with measures of social stratification in person characteristics, markers of stratification in the person and the environment help explain risk for slower gait.

Model-5 found slower gait for those with a BMI $\geq$ 30 (when compared to those with a BMI 18.5 to 24.9) and current smokers (when compared to life-time abstainers). Slower gait was also found for those reporting diabetes, hypertension, who feel pain when walking, reports having fall in past 12 months, who report having slowed down activities in past 12 months because of health conditions. Faster gait speeds were found for married individuals, those with higher educational attainment, for current alcohol drinkers (when compared to life-time abstainers), reporting more physical activity, and for individuals with higher scores on the 3MSE. In terms of social determinants of health, a *higher* risk for abnormal gait may be found in non-married African American females with limited educational attainment who reside in an area where $\geq$30% of people live in-poverty. A *lower* risk for abnormal gait is found in married white males with high educational attainment who reside in an area where $\leq$9% of people live in-poverty.

Table 3. Relationship between environmental exposures and gait speed

	Model-4		Model-5	
Level of Poverty				
≤9%	Ref		Ref	
10%-19%	-0.03	*	-0.01	
20%-29%	-0.06	***	-0.01	
≥30%	-0.08	***	-0.02	*
Street Connectivity				
Low (Q1)	Ref		Ref	
Below average (Q2)	-0.01		0.02	
Above average (Q3)	-0.03	*	-0.01	
High (Q4)	-0.02		0.01	
Net Residential Density				
Low (Q1)	Ref		Ref	
Below average (Q2)	-0.02		-0.02	
Above average (Q3)	0.00		0.00	
High (Q4)	0.00		0.02	
Age			-0.01	***
Female			-0.09	***
White			0.10	***
Married			0.02	***
Educational Attainment			0.01	***
Body Mass Index				
≤18.4			0.00	
18.5 to 24.9			Ref	
25 to 26.9			0.01	
27 to 29.9			-0.01	
≥30			-0.03	***
Tobacco Smoking				
Never			Ref	
Former			-0.01	
Current			-0.07	***
Alcohol Drinking				
Never			Ref	
Former			0.00	
Current			0.02	*
Physical activity (logged kcal/wk)			0.02	***
Diabetes			-0.03	*
Hypertension			-0.02	**
Stroke			-0.10	***
Asthma			-0.03	*
Arthritis			-0.01	
Activity slowed in past 12 months			-0.02	*
Has fallen in past 12 months			-0.03	***
Has difficulty stooping or kneeling			-0.04	***
Feels leg pain when walking			-0.04	***
Cognition (3MS)			0.01	***
Emotional status (CES-D)			0.00	
Intercept	1.24	***	1.67	***
R2	0.02	***	0.29	***

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

4.0 CONCLUSIONS

We began by explaining that measures of the social, built, and physical environment matter for aging research because they reflect where personal resources place an individual within their socio-ecosystem. We argued this system of social arrangements is reflected in how individuals are distributed between health-heterogeneous geographies. Place of residence may be important because attributes of the environment may be capable of reinforcing advantages or aggravating disadvantages in the formation, maintenance, and/or eradication of physical well-being.

We explained that locating an individual's position within the social-ecosystem demanded the use of ecological measures—i.e., attributes of the environment. Within this conceptual framework, our study sought to identify environmental risk factors for abnormal gait speed to inform health policies aimed at reducing prevalence and severity of mobility disability in community-dwelling older adults. We found poverty concentration in residential area helps explain between-people difference in gait speed. In particular, we found residing in a poverty-concentrated environment is a risk factor for abnormal gait—above and beyond a person's socioeconomic characteristics, health behaviors and conditions. Our study supports previous findings [Shumway-Cook—Becerra; Clarke—Beard] showing adverse physical function is more prevalent in resource-poor environments.

Authors have argued a 0.05 m/sec difference in gait speed is small but clinically meaningful [Perera 2006]. The independent effect of -0.02 m/sec from a ≥30% poverty concentration may not be considered clinically meaningful by some researchers. The small effect should also be considered from an etiological perspective. Although small, the effect of residing in an economically disadvantage environment may, after years of exposure, hasten the onset of pathogenesis in abnormal gait and speed up progression to ambulatory incapacity. In other words, the small risk for gait speed from residing in an economically disadvantaged environment may accumulate over many years to substantially affect functional decline in disability trajectories.

There are some limitations with our study. Because we do not assess causality, we fail to answer an important question in health and place research: Do individuals have poor health because they reside in low-resource environments or do they reside in disadvantage places because they have poor health? A popular view is that social disadvantage may most frequently precede adverse health that vice versa [Siordia 2015]. Future work should take advantage of the longitudinal data in the Health ABC Study to infer causality between environmental exposures and physical function. For example, attributes of baseline residential environment may help explain more variance in within-person trajectories of physical function than cross-sectional variance in gait speed.

The fact that our environmental exposure had such a small effect on gait speed should not be interpreted as indicating ecological measures are uninformative risk factors. Our study is limited in that measures of the "residential environment" include large geographical areas—as the use of tracts was mandatory in the measurement of poverty. As a result, street connectivity and residential housing density may represent ambiguous measures of the built environment.

Future work should seek to develop measures of the environment using smaller geographical units and with more specific measures of the physical and built environment.

It is beyond our current discussion to detail how participation with studies on aging may produce geo-spatially non-representative samples [Mobley 2013; Chaix 2010; Chaix 2011; Chaix 2013]. It is, however, important to note epidemiologist have explained using geographical approaches in sample selection may help better “study interactions between spatial characteristics and health outcomes” [Vallée 2007]. In truth, isolating the effect of the environment on gait speed may be difficult because “social processes or exposure to specific environments, do not leave a pathological footprint as we currently measure them” [Rosso 2013cns]. Future studies should seek to ascertain how geo-spatially representative their sample is and the degree to which participants have experienced a heterogeneity in environments over the life-course.

Notwithstanding limitations, our study is novel because it investigates the association between observed gait speed and objective measures of the residential environment. In our study, slower gait was found to be most prevalent in areas with more economic disadvantage. Social disadvantage and adverse health may fuel each other amongst those with limited life chances in early-life. Because health equity is an issue of social justice [Braveman 2011], one of Healthy People’s 2020 overarching goals is to *eliminate* health disparities among Americans [Healthy 2020]. Accounting for the environment has been deemed so imperative for public health’s impact that the Centers for Disease Control and Prevention created the Environmental Public Health Tracking (EPHT) program [Mcgeehin 2008]. The EPHT is a nationwide surveillance system focusing on the environment’s impact on human health [Hinojosa 2014]. Our study informs on how the residential environment is associated with physical function.

Studying the relationship between physical function and the environment is important for public health. Population-wide interventions have the greatest potential for impacting public health. If the principal of ‘equal worth’ amongst humans is to be embrace in democratic societies, then health equity must improve as physical well-being is essential for maximizing life potentials. Consequently, an aim of Healthy People 2020 is to “create social and physical environments that promote good health for all” [Healthy 2020]. Our study suggests socioeconomically disadvantaged areas should be targeted for reducing between-group differences in physical function.

The social determinants approach, in Healthy People 2020, is built on the philosophy of *shared societal responsibility* [Koh 2011]. Addressing social determinants to impact public health may require challenging established political and economic power structures. To achieve wider impact, public health must continue to address peoples’ agency (behavior modification request) and the social structures (economic disadvantage) that limit their ability to control their own health. Improving socioeconomic equity may help with communicable disease in the population by reducing exposure to harmful environmental factors like microbes and crime [Cutler 2005]. Advancing economic equity may also help with noncommunicable disease in the population by increasing educational attainment, improving nutrition, and promoting beneficial health behaviors [Frieden 2010].

As evident by our results, both person and place characteristics help explain between-people variance in gait speed. The geographical concentration of economic disadvantaged is found to be a risk factor for gait speed. Public health policies and health professionals should continue to invest resources in residents of financially challenged neighborhoods to help mitigate prevalence of disability. Promoting built, social, and physical environments that promote good health may help public health significantly reduce decease in the population. Because genes, biology, random events, and the environment affect health, ignoring PE_t in $Gait\ Speed = \int(P_t, E_t, PE_t, R_t)$ may prohibit epidemiologist from identifying the etiology of abnormal gait. Social disadvantages, in the person and the environment, can get into the body to result in decease. Establishing mechanisms for abnormal gait requires the inclusion of social determinants of health.

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