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Association of the Spatial Layout of the Home and ADL Abilities Among Older Adults With Dementia

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Abstract

We investigated the relationship between architectural space syntax measures describing the spatial layout of a home and activities of daily living (ADL) among people with dementia. We visited the homes of 82 participants in a dementia care comparative effectiveness clinical trial and measured the space syntax variables intelligibility and convexity along with several clinical variables, including ADLs. In regression models, we estimated the cross-sectional association between space syntax measures and ADLs. Higher convexity was associated with worse performance of basic but not instrumental ADLs (adjusted $\beta = 19.2$, $P = .02$). Intelligibility was not associated with ADLs. These results imply that enclosed rooms with a clearly legible meaning and function might be better memorized and associated with the spatial layout of the home resulting in better basic ADL performance. These results warrant further research on space syntax measures in the home environment of people with dementia, including longitudinal study, which we are pursuing.

Keywords

dementia; space syntax; home environment; function; activities of daily living

Introduction

Aging in place, meaning the ability of individuals to remain in their home in the community, is a consistent wish and expectation of middle aged and older people.¹ In 2002, the prevalence of dementia among individuals aged 71 and older was 13.9% and comprised 3.4 million individuals in the United States.² It is estimated that about 73% of all older adults with dementia are cared for in their own home.³ With the aging population, research in home environments has developed a new focus of environmental gerontology which includes professionals with backgrounds in anthropology, architecture, geography, occupational therapy, psychiatry, psychology, and other fields.

In a recent review on the empirical evidence published between 1997 and 2006, Wahl et al⁴ identified evidence for a relationship between home environments and disability-related

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outcomes for older adults. The presumption that improving home environments enhances functional ability outcomes was also supported. However, inconsistencies in findings across studies, the limitation of cross-sectional designs, and, to some extent, insufficient research quality were noted. Several other authors have addressed the lack of empirical studies on home environments in dementia and also acknowledge the challenges of conducting research of this type.^{3,5,6} Gitlin⁵ identified the development of appropriate measures as one of the critical directions for further research. In the field of institutional settings, many assessment and design audit tools have been developed to obtain measures on the physical environment.⁷⁻¹⁰ In contrast, very few tools, such as the Home Environmental Assessment Protocol (HEAP)¹¹ are available for use in the individual community home. Regardless of their intended field of application, these tools typically target physical features as well as hazards in the persons' environment and give little attention to the spatial configuration of the home. Also, most of the research seems to focus on older adults with age-related functional losses and only a few publications address the specific needs of people with dementia.¹²⁻¹⁴ However, first design concepts, incorporating among others a dwelling's architecture and interior design, have been published.¹⁵

Evidence of a relationship between the design of institutional settings and functionality, independence, well-being, or behavior in people with dementia has been established in several studies. Physical features such as a small group size, residential design, privacy, and safety and accessibility have been empirically linked to a higher level of independence, less agitation and aggression, and less psychosis.¹⁶⁻¹⁹ Additionally, the spatial layout of the institutional environment is positively correlated with wayfinding and vitality.²⁰⁻²³ These findings are supported within the framework of the ecological theory of aging,^{24,25} which postulates that human behavior and functionality result from the individual's competencies, the demands of the environment, and the interaction or adaptation of the person to the environment.

In Maximizing Independence At Home (MIND at Home) Phase 1, a pilot study, environmental safety was found to be one of the most prevalent areas of need among home-dwelling persons with dementia.²⁶ In the study presented here, we use data from MIND at Home Phase 2 comparative effectiveness clinical trial to investigate the relationship between space syntax, a measure that allows the assessment of the spatial layout of an individual home from the inhabitants' point of view, and performance of activities of daily living among community-living older adults with dementia. This is the first application that we know of that examines whether the established space syntax architectural methodology²⁷ is a predictor of clinical outcomes among older persons with dementia. The general idea of space syntax is that spatial configurations can be broken down into components and represented as graphs that describe the relative integration and connectivity of convex spaces (here: rooms) within a given system (here: the house). Space syntax measures the degree to which a room is connected and integrated into the whole spatial system of the home (intelligibility—INTELL) and how much the whole system is "broken up" into different spaces and rooms (convexity—CNVX). We hypothesized that individuals living in homes with high INTELL and low CNVX would exhibit a higher level of functioning, in both instrumental and basic activities of daily living.

Methods

Participant Sample

We report on cross-sectional data derived from a larger, ongoing, randomized controlled trial (MIND at Home) designed to evaluate the effectiveness of a dementia-oriented care coordination intervention on unmet needs and ability to age in place among a cohort of community-dwelling older adults with cognitive disorders. A detailed description of the trial

methodology will be forthcoming. In brief, the full sample consists of 303 older adults living in 1 of 28 contiguous zip code areas in North/Northwest Baltimore. Participants were recruited from aging services providers, local government social service agencies, community centers and day programs, clinics, and senior housing. Supplemental recruitment notices also appeared in local media sources to provide background promotion of the study. The inclusion criteria for participants were as follows: (1) residence in the identified catchment area, (2) aged 70+, (3) met Diagnostic and Statistical Manual of Mental Disorders (Fourth Edition, Text Revision; *DSM-IV-TR*) criteria for any type of dementia or cognitive disorder not otherwise specified (Cognitive DO NOS), and (4) a reliable study partner was available to serve as a proxy informant (ie, someone who knows the participant, who interacts with him or her regularly, and is willing to participate. Study partners included spouses, children, and other informal carers). Individuals were excluded if they (1) were non-English speaking, (2) if the situation at the time of referral involved a crisis with risk of danger to the individual or others, or (3) if medical morbidity or substance use could not be ruled out as a cause for cognitive impairment.

The current analytic sample is a subset of this cohort comprising 82 MIND at Home Phase 2 participants who received—between August and December 2009—an in-home assessment by a PhD architect (GM the lead author) trained in space syntax measurement. All study procedures were reviewed and approved by an Institutional Review Board at the Johns Hopkins School of Medicine. Oral consent was obtained from participants in the phone screening stage and written consent was obtained during the initial in-person visit. In cases where capacity to consent was compromised, consent was obtained from a legally authorized representative (LAR) using the Maryland Health Care Decisions act as a guide, and written or oral assent was obtained from the participant.

The study enrollment process consisted of a 15-minute phone screening for cognitive impairment followed by a comprehensive in-home clinical assessment to determine the presence of dementia or cognitive DO NOS, along with an assessment of 15 dementia-related needs across multiple domains. The clinical assessment team was overseen by a geriatric psychiatrist (DJ) and performed by a nurse experienced in dementia care. The initial in-home clinical assessment included medical and neuropsychiatric history, mental status and neurological examination, and medication review to determine diagnoses. Information was gathered from the participant, the study partner, and from medical reports, when available. If found eligible, baseline quantitative clinical measures were assessed (see below), followed by randomization into 1 of 2 groups, care coordination or care as usual (control). A written summary evaluation of unmet needs and potential interventions was sent after the randomization to all participants and/or their LAR, and, with permission, to their primary care providers. Routine follow-up assessments for all participants were completed or planned at 4.5, 9, 13.5, and 18 months by blinded assessors.

Space syntax, operationalized as intelligibility or convexity, was measured during in-home visits in a sample of convenience for 82 participants (57 at baseline visit, 25 at the 9-month visit). For the transformation of the floor plan into a convex map and ultimately into a numeric description, the following procedure was performed for each home visited (Figure 1a). Every convex space was assigned a node. Filled circles represent a room with a meaning (ie, living room, kitchen), unfilled circles denote circulation areas such as steps, hallways, etc. Nodes were connected by lines wherever direct access from one room to another was possible. Figure 1b shows the resulting convex map.

To assess the participant perception of spatial layout, the space where the care recipient spends most of his or her time was identified as the important space within the convex map and all further measures were calculated using this node. Therefore, a justified map was

produced in which one point is put at the base and all other points are aligned according to their depth from this point (Figure 1c).

From those maps, space syntax measures of the participants' homes were calculated. The basic variable is the depth of one space from another. The mean depth (MD) of the map is calculated by assigning a depth value to each space according to how many spaces it is away from the original space (here: the place in the home where the participant spends most of the day).²⁷ Mean depth is then used to calculate the relative asymmetry (RA), which is a comparison of how deep the system is from a particular point with how deep or shallow it theoretically could be, k stands for the number of cells (rooms) in the system (house): $RA = 2(MD - 1)/(k - 2)$. Low RA values indicate a space from which the system is shallow and the space is well integrated into the system, while high values indicate spaces that tend to be segregated from the system.²⁷ To compare measures from homes with different numbers of rooms, it is necessary to compute the Real Relative Asymmetry (RRA), which is a ratio of the RA values of a given system (here: the house) and the RA values (called D_k) of a system with a normal distribution, for which the central node of a diamond shaped graph with the same number of nodes as in the system is used: $RRA = RA/D_k$.^{27,28} Space syntax studies typically report integration (INT) values, which are the inverse of the RRA values: $INT = 1/RRA$. Higher integration values of nodes indicate that the node is less deep on average from all other nodes, meaning, that it is more integrated into the spatial system.²⁸

For this study, in each home the integration value for the care recipients' place was calculated. Another measure we computed was a local property of the care recipients' place, which is called connectivity. It is the number of spatial units (rooms / nodes) that are directly accessible from a place.²⁸ For a comprehensive description of the care recipients' place, a combination of its integration value and connectivity becomes necessary. Space syntax research reports on intelligibility, which describes the degree of correlation between connectivity and integration values and can be used as a measure of the predictability of the environment.²⁸ To compute the measure of intelligibility (INTELL), we standardized both the variables for the integration value and the connectivity by subtracting the minimum value and dividing by the range. The results were 2 transformed variables in the range between 0 and 1. Their mean was computed to obtain the variable INTELL. We checked the reasonableness of these transformations by confirming that the r -squared between the 2 untransformed variables as well as between the 2 transformed variables was the same.

Convexity (CNVX), another space syntax measure, was also calculated. In urban space syntax studies, the measure of convexity is a ratio of the number of all convex spaces within the system and the number of buildings. In this study, this concept was applied to homes, as a ratio of the number of all convex spaces within the home (including all rooms, and circulation areas, stairs etc) and the number of rooms with a function and meaning (ie, kitchen, bedroom, dining room). Higher scores indicate more broken up systems with a high number of convex spaces but few rooms with an assigned meaning. Lower scores account for less broken up systems, where most convex spaces are rooms with an assigned meaning.

All participants were also assessed around the same time as the space syntax measures on a range of well-established clinical measures as part of the MIND at Home project. Day-to-day functioning was measured by the Instrumental Activities of Daily Living Scale (IADLS),²⁹ a widely used measure of instrumental activities of daily living, and the Psychogeriatric Dependency Rating Scale (PGDRS)³⁰, a measure of basic activities of daily living. Cognitive functioning was assessed using the Mini-Mental State Examination (MMSE)³¹, a scale of global cognitive functioning. Participant demographics including age, sex, race, and years of education were also recorded. The presence of a caregiver, defined as a person who knew the person well, who had at least weekly contact and on whom the

person relied for assistance, and whether the participant was currently residing with the caregiver were also determined during the initial assessment. Other relevant variables such as housing type and years in current residence were recorded.

Analytic Plan

Descriptive statistics were computed to determine the normality, mean, variance, and/or range of the variables. INTELL and CNVX were the principal independent variables. Their distributions were positively skewed. Log transformations (ln) were performed on these to normalize their distributions. The log-transformed scores were used in the subsequent analyses. Demographic variables (age, sex, race, years of education), presence of a caregiver in the home (dichotomous), years residing at current residence (continuous), and cognitive function were examined as potential covariates. Uni- and multivariable linear regression analyses were employed to estimate the association between space syntax and basic activities of daily living, with and without adjustment for other covariates with instrumental activities. Variables found to be significant ($P < .05$) in the univariable analyses were entered into models of hierarchical multivariate regression to estimate the relative independent contribution of each.

Results

Participants

The mean age of participants was 84.5 years (SD = 5.8). The majority were women with 62%. Most were married (62%), 29% were widowed, 6% divorced, and 3% never married. The racial composition of the sample was 77% Caucasian and 23% African American. Half of the participants lived in single-family homes, 28% in apartments, and 22% in townhouses. Nearly three quarters (73%) lived with a caregiver, 13% alone, and 13% with another person who did not meet the definition of a caregiver. Study partners (who may or may not have also been caregivers) were mainly spouses (44%) or adult children of the participants (37%). The vast majority of study partners (96%) were also the participants' caregiver. All participants met the criteria for dementia. Assigning stages,³² 44% of participants ($n = 36$) had mild dementia (MMSE score 21 and above), 38% ($n = 31$) had moderate dementia (MMSE score 11-20), and another 17% ($n = 14$) had severe dementia (MMSE score 0-10).

Descriptive data on the participants' instrumental and basic activities of daily living and their home's space syntax measures are in Table 1.

Results of Univariable Linear Regression Models

Results of univariable models examining the association between the space syntax variables and covariates with IADL and the PGDRS are in Tables 2 and 3, respectively. Mini-Mental State Examination and living with a caregiver were the strongest univariable correlates of IADL scores while demographics did not contribute significantly nor did INTELL and CNVX. For PGDRS, MMSE, female, and CNVX score were significant univariable contributors.

Even though intelligibility was not significant in either univariable model and convexity was significantly related to only PDGRS, both variables were included in the multivariable linear regression models since they were hypothesized a priori to be predictors of ADLs. Results are in Tables 4 and 5.

Mini-Mental State Examination and living with a caregiver were significant predictors of IADL scores and accounted approximately for 39% of the variance. In the multivariate

regression model for PGDRS, MMSE was again significant, as well as CNVX, and together they accounted for a third of the variance in scores (33%). With a β of 19.2 as effect size, a 1-point increase in CNVX accounts for an increase of the PDGRS by 19 points, making the person with dementia more dependent on a caregiver. Since the average of CNVX in this sample is 1.33 and the standard deviation 0.14, the possible effect on the PDGRS would be an increase of 3 points: $(0.14) * (19.241) = 2.694$. This could mean that an individual without ADL dependency initially might become fully dependent on others for dressing.

Discussion

This cross-sectional study evaluated the association between environment and functioning at home in older adults with dementia using space syntax methods. The results provide support for our main hypothesis, that there is a relationship between space syntax measures describing the layout of the home and the participant's level of functioning, even though, as stated in previous studies,³³ the presence of a partner in the home is an important parameter. We found that increased convexity of a place, meaning that the spatial system is broken up into various convex spaces, was associated with increased functional dependency in basic activities of daily living of the inhabitant. This means that residents who live in a home that features a high proportion of open spaces, such as circulation areas and interconnected rooms, and fewer enclosed rooms with a clearly legible meaning and function were more dependent on others with their basic activities of daily living, such as eating, dressing, using the bathroom. One possible explanation for this might be found in the spatial representations of people with dementia. We hypothesize that homes that consist of mainly enclosed rooms with a clearly legible meaning and function form a spatial system that can better be memorized, resulting in more successful navigation of the place. Also, rooms associated with purpose may cue individuals in performance of activities of daily living. Of note is that convexity was only related to basic activities of daily living such as toileting and bathing and not more complex instrumental activities such as meal preparation and paying bills. However, the individual living situation, whether the participant lived with a spouse or other caregiver, also contributed to lower instrumental activities of daily living.

Against our expectations, we found no association between the intelligibility of the participants' places and their level of functioning. We hypothesize the reason might be that other aspects of the usability of the home we were not able to measure have to be taken into account as well, especially the absence of physical barriers, such as steps, lengths and widths of hallways and rooms, and door widths. Though our hypothesis that there is an association between the space syntax measures and the inhabitant's level of functioning was only partially supported, this exploratory study shows promising results that might contribute to a better understanding of spatial recognition in people with dementia: Spatial systems with a high convexity, that are very open and interconnected, might account for difficulties in spatial representation and therefore lead to a higher level of dependency on a caregiver. Spatial systems with a lower convexity, that feature mainly enclosed spaces with an assigned meaning, maybe more easily perceived and memorized and therefore result in a better level of functioning. Whether a less convex home enables people with dementia to live in their home for a longer time can only be hypothesized at this point and will be evaluated in a longitudinal follow-up. Adapting the home to the needs of people with dementia would then also encompass decreasing the home's convexity perhaps by concentrating spaces and giving them an assigned meaning. Options could include separating the circulation area from the living or dining room by using different flooring, rendering them very distinct from another. Using articulate colors, lighting, and, maybe decorations, might also contribute to a clearer legibility of the meaning and the function of rooms, or moving the location of meaningful areas to other places, such as moving the bedroom to a lower level and/or changing the use and purpose of rooms where the residents

spend much of their time. Architects who design homes should allow for spatial flexibility to cater to the individual's needs over their lifespan. This gains increasing importance with the "graying of America," which leads to an increasing number of older adults with dementia and will ultimately result in a growing demand for suitable housing.

Limitations

One potential source of bias in this study is the possibility that being in the study influenced environmental changes in participants' homes prior to the space syntax measurements. For example, all participants had received a visit from the clinical study team related to unmet dementia-related needs, and some may have received verbal advice on environmental hazards such as need for reduction of clutter and removal of fall risks, which they may have modified prior to the baseline visit and the assessment of space syntax. Also, 25 participants had been enrolled in the study for 9 months prior to the space syntax measurement, during which time they had received a written letter of recommendations that may have included advice on environmental hazards. Also, this group may have been receiving advice from the study team on potential home modifications. We performed a sensitivity analysis to test for this potential bias by computing the univariate and multivariate linear regression models using data from individuals whose space syntax measures were collected during baseline ($n = 57$) while excluding data from participants visited at 9th month ($n = 25$). The results showed no differences in the contributions of space syntax variables to ADLs suggesting that the duration of study participation did not affect results.

In this study, space syntax measures of a home have been used for the first time to predict clinical outcomes for people with dementia. At this point, only cross-sectional data are available, but in a next step those will be expanded to longitudinal associations, which may support stronger conclusions.

Recommendations for Further Research

The space syntax variables intelligibility and convexity give a numeric description of the spatial layout of the home. Many other important dimensions of a home, such as place attachment, meaning, past memories, values, and control are not represented. Also, the usability of the home, which encompasses a barrier-free design, or at least the absence of major barriers, is not taken into account. Only limited research in the latter domains is available in the literature^{34,35} and further research could focus on the development of spatial measures that integrate models with domains of the home as perceived by the individual.

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Figure 1.

a, Floor plan of an exemplary home. The participant spends most of her time on the ground floor, in the dining room. b, Convex map of the home. Blank nodes represent circulation areas and stairs, solid nodes represent rooms with an assigned function / meaning. c, Convex map of the home, justified to the care recipients' place. Depth levels (0-4) are assigned to all spaces in relation to the participant's place.

Table 1

Descriptive Data on Participant's Outcomes and Their Home's Space Syntax Measures

Measure	Mean	SD
Participant		
IADL	23.44	5.50
PGDRS	10.79	8.66
MMSE	17.79	7.69
Participant's home		
CNVX	1.33	0.14
INTELL	0.27	0.20

Abbreviations: IADL, instrumental activities of daily living scale; PGDRS, psychogeriatric dependency rating scale; MMSE, mini-mental state examination; CNVX, convexity; INTELL, intelligibility.

Table 2

Results of Univariable Linear Regression Models With the IADL as Dependent Variable

Independent Variable	B (SE)	P	R ²
INTELL	0.931 (.771)	.231	.018
CNVX	9.296 (5.752)	.110	.032
MMSE	−0.420 (.065)	< .001	.348
Current living status with CG	4.479 (1.288)	.001	.133
Age	−.060 (.107)	.572	.004
Race	2.789 (1.418)	.053	.047
Sex	−1.659 (1.260)	.192	.021
Years of education	−0.241 (.183)	.192	.021
Years at current residence	0.005 (.033)	.877	.000

Abbreviations: IADL, instrumental activities of daily living scale; MMSE, mini-mental state examination; CNVX, convexity; INTELL, intelligibility; CG, care giver.

Table 3

Results of Univariable Linear Regression Models With the PDGRS as Dependent Variable

Independent Variable	B (SE)	P	R ²
INTELL	−0.353 (1.225)	.774	.001
CNVX	29.249 (9.030)	.002	.119
MMSE	−0.622 (.107)	<.001	.301
Current living status with CG	4.152 (2.161)	.058	.045
Age	−.0150 (.169)	.376	.010
Race	2.199 (2.273)	.336	.012
Sex	−4.102 (1.939)	.038	.054
Years of education	0.143 (.291)	.625	.003
Years at current residence	0.028 (.052)	.592	.004

Abbreviations: PGDRS, psychogeriatric dependency rating scale; MMSE, mini-mental state examination; CNVX, convexity; INTELL, intelligibility; CG, care giver.

Table 4Multivariable Linear Regression Models With the IADL as Dependent Variable^a

Independent Variables	B (SE)	P
MMSE	-.377 (.063)	<.001
Current living status with CG	2.294 (1.075)	.036
INTELL	.760 (.608)	.215
CNVX	2.030 (4.706)	.667

Abbreviations: IADL, instrumental activities of daily living scale; MMSE, mini-mental state examination; CNVX, convexity; INTELL, intelligibility; CG, care giver.

^aThe complete model accounted for an adjusted $R^2 = .388$.

Table 5Multivariable Linear Regression Models With the PGDRS as Dependent Variable^a

Independent Variables	B (SE)	P
MMSE	-.523 (.111)	<.001
Sex	-1.789 (1.747)	.309
INTELL	-.443 (1.057)	.676
CNVX	19.241 (8.316)	.024

Abbreviations: PGDRS, psychogeriatric dependency rating scale; MMSE, mini-mental state examination; CNVX, convexity; INTELL, intelligibility.

^aThe complete model accounted for an adjusted $R^2 = .325$.