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Original Contribution

Life-Space Constriction, Development of Frailty, and the Competing Risk of Mortality

The Women's Health and Aging Study I

Qian-Li Xue[1,2], Linda P. Fried[1,2], Thomas A. Glass[3], Alison Laffan[3], and Paulo H. M. Chaves[1,2]

[1] Department of Medicine, School of Medicine, Johns Hopkins University, Baltimore, MD.
[2] Center on Aging and Health, Johns Hopkins Medical Institutions, Baltimore, MD.
[3] Department of Epidemiology, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD.

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Frailty is a common clinical syndrome in older adults that carries an increased risk for poor health outcomes. Little is known about the behavioral antecedents of frailty. In this study, the authors hypothesized that constriction of life space identifies older adults at risk for frailty, potentially a marker of already-decreased physiologic reserve. The authors analyzed the 3-year (1992–1995) cumulative incidence of frailty using a previously validated clinical phenotype in relation to baseline life-space constriction among 599 community-dwelling women aged 65 years or older who were not frail at baseline. Frailty-free mortality (i.e., death prior to observation of frailty) was treated as a competing risk. Multivariate survival models showed that, compared with women who left the neighborhood four or more times per week, those who left the neighborhood less frequently were 1.7 times (95% confidence interval: 1.1, 2.4; $p < 0.05$) more likely to become frail, and those who never left their homes experienced a threefold increase in frailty-free mortality (95% confidence interval: 1.4, 7.7; $p < 0.01$), after adjustment for chronic disease, physical disability, and psychosocial factors. Together, these data suggest that a slightly constricted life space may be a marker and/or risk factor for the development of frailty that may prove useful as a screening tool or a target of intervention.

adaptation, physiological; aged; frail elderly; homebound persons

Abbreviations: ADL, activities of daily living; IADL, instrumental activities of daily living; MMSE, Mini-Mental State Examination; WHAS I, Women's Health and Aging Study I.

Reduction in physiologic reserve due to accumulation of impairments across multiple physiologic systems has been postulated to play a key role in the development of frailty—a major clinical syndrome in older adults with severe health consequences (1, 2). Mobility limitation has been recognized as a key component of frailty in the major conceptual and operational frameworks published in the literature, across the varying definitions proposed for frailty (2–6). Recently, we obtained empirical evidence that slowed walking speed and a low level of physical activity were among the earliest clinical manifestations of frailty (Qian-Li Xue, Johns Hopkins University, unpublished manuscript). In this context, easy-to-obtain measures of mobility may prove useful in identification of older adults who are becoming clinically vulnerable at a relatively early stage of the frailty process, when preventive intervention could be easiest to implement and theoretically most effective.

Life space, a relatively understudied concept in gerontology, can be defined as the size of the spatial area a person purposely moves through in his/her daily life, as well as the frequency of travel within a specific time frame (7, 8). Unlike the conventional measures of mobility function such as

Correspondence to Dr. Qian-Li Xue, Johns Hopkins School of Medicine, 2024 E. Monument Street, Suite 2-700, Baltimore, MD 21205 (e-mail: qxue@jhsph.edu).

fixed-distance or fixed-time walking tests, life space is a direct assessment of enacted function in the real world, rather than functional capability under hypothetical or experimental conditions (9). Therefore, assessment of life space may reflect actual mobility performance, taking into account the balance between internal physiologic capacity and external challenges older adults experience in daily life (7, 9); this is not typically captured by self-reports of mobility difficulty or dependency or timed walking tests.

The broad hypotheses underlying our line of investigation were that constricted life space is a marker of declines in physiologic reserve among persons who are at risk of developing frailty and that constriction of life space itself could lead to deconditioning and, in turn, augment the development of frailty. To begin addressing these questions, we assessed the association between baseline life-space constriction and cumulative incidence of frailty over a 3-year period using data from the Women's Health and Aging Study I (WHAS I).

MATERIALS AND METHODS

Study population

WHAS I is a prospective, observational cohort study of 1,002 community-dwelling women aged 65 years or older who were moderately or severely disabled at baseline (1992). The study subjects were recruited from an age-stratified sample of Medicare beneficiaries in 12 contiguous zip codes of Baltimore City and Baltimore County, Maryland. Eligibility criteria included self-reported difficulty in at least two of four domains of physical function (mobility, upper extremity, high functioning, and self-care tasks) and a Mini-Mental State Examination (MMSE) score of 18 or higher (10). Standardized questionnaires and physical examinations were administered in participants' homes at baseline and at six follow-up examinations conducted 6 months apart; this resulted in an average follow-up time of 3 years (1992–1995). The study was approved by the Johns Hopkins University's institutional review board, and all participants gave written informed consent. The current analyses were restricted to a subset of 599 women who were not frail at baseline and had at least one follow-up visit.

Frailty phenotype

We used the same frailty phenotype that was originally proposed in the Cardiovascular Health Study (2) and later validated using available WHAS I measures (1). The frailty phenotype consists of five binary criteria: weakness, slowness, low physical activity, weight loss, and exhaustion. We employed the same criterion-specific thresholds for defining onset over time as were used in the WHAS I cross-validation study (1), except for weight loss, which we defined as experiencing unintentional weight loss of at least 5 percent between examinations spanning 12-month intervals or having a body mass index (weight (kg)/height (m)^2) below 18.5. As in the Cardiovascular Health Study, we classified women meeting three or more of these criteria as frail. Frailty status was assessed at baseline and yearly thereafter, for a maximum of four measurements per participant over the course of the study. This phenotype has been shown to be consistent with the theory that conceptualizes frailty as a clinical syndrome distinct from disease and disability (1, 2).

Life-space assessment

We used an abbreviated instrument adapted from Stalvey et al.'s Life Space Questionnaire (11) to assess spatial mobility. Specifically, the size of the participant's life space was ascertained using two questions: "During a typical week, do you leave your neighborhood?" and "During a typical week, weather permitting, do you go outside the house?". Participants responding "yes" to either question were asked a follow-up question regarding the frequency of these activities. Based on these questions, a four-level ordinal scale was created: severely constricted (never left the house; $n = 51$), moderately constricted (left the house but remained in the neighborhood; $n = 107$), slightly constricted (left the neighborhood less than four times per week; $n = 247$), and not constricted (left the neighborhood four or more times per week; $n = 194$). The proposed life-space scale was recently validated in WHAS I, showing good construct and criterion validity (12).

Covariates

To assess the independent effect of life-space constriction on frailty above and beyond comorbidity, disability, and mental health, we included the following covariates in multivariate-adjusted analyses.

Chronic diseases and physical and cognitive function. The presence or absence of 14 major chronic diseases and conditions was adjudicated by physicians on the basis of predefined criteria (10) (see the fourth footnote in table 1 for specific diseases). The number of "definite" conditions, out of 14, was used as a summary measure of disease burden.

Physical function was assessed by means of self-reported difficulty with at least one of the given tasks in each of three domains: activities of daily living (ADL), instrumental activities of daily living (IADL), and mobility. Cognitive function was measured by MMSE score.

Psychosocial characteristics. Depressive symptoms were assessed using the 30-item Geriatric Depression Scale (13). Women with scores of 14 or above were considered at elevated risk of depression. Anxiety was present if women answered "yes" to two or more of the following four questions: "During the past week, 1) have you felt nervous or shaky inside; 2) have you had to avoid certain things, places or activities because they frighten you; 3) have you felt tense or keyed up; 4) have you felt fearful?" Personal mastery was defined as agreeing or strongly agreeing with the statement "I can do just about anything I set my mind to" and disagreeing or strongly disagreeing with the statement "I often feel helpless in dealing with the problems of life" (14).

Statistical analyses

The primary outcome for this study was incident frailty, defined as the first study visit at which three or more of the

TABLE 1. Demographic and health characteristics of 599 women who were not frail at baseline and had at least one follow-up visit, by degree of life-space constriction, Women's Health and Aging Study I, 1992–1995

Variable	Degree of life-space constriction				*p* value*
	Not constricted ($n = 194$)	Slightly constricted ($n = 247$)	Moderately constricted ($n = 107$)	Severely constricted ($n = 51$)	
Mean age (years)	74.6 (6.8)†	76.4 (7.3)	78.4 (7.7)	80.1 (9.2)	<0.01
Race (% Black)	20.6	28.3	35.5	52.9	<0.01
Mean years of education	11.3 (3.9)	9.8 (3.3)	8.9 (3.8)	8.9 (3.4)	<0.01
Mean annual income (×$1,000)	22.4 (21.2)	15.2 (13.8)	13.5 (13.0)	10.5 (7.1)	<0.01
Living alone (%)	48.5	47.8	52.3	41.2	0.62
Mean MMSE‡ score	27.8 (2.3)	26.7 (2.8)	26.3 (3.0)	25.8 (3.4)	<0.01
MMSE score (%)					
<24	5.7	11.7	21.5	29.4	<0.01
≥24 and <27	18.0	31.6	22.4	21.6	
≥27	76.3	56.7	56.1	49.0	
Mean no. of chronic diseases§	2.3 (1.2)	2.2 (1.3)	2.3 (1.3)	2.6 (1.4)	0.32
Disease type¶ (%)					
Cardiovascular	39.7	42.1	40.2	56.9	0.16
Musculoskeletal	53.6	50.6	53.3	43.1	0.58
Neurologic	4.6	6.5	5.6	15.7	0.04
Pulmonary	27.3	28.7	26.2	29.4	0.95
Diabetes mellitus	10.8	14.6	21.5	19.6	0.07
Cancer	13.4	11.3	6.5	5.9	0.19
Anxiety (%)	15.0	12.2	17.8	13.7	0.56
Personal mastery (%)	71.7	66.4	58.9	45.1	<0.01
Geriatric Depression Scale score ≥14 (%)	6.7	8.5	23.4	18	<0.01
Difficulty with activities of daily living# (%)					<0.01
None	38.7	41.7	43.9	25.5	
A little/some	46.4	36.4	29.0	9.8	
A lot/unable	15.0	21.9	27.1	64.7	
Mobility difficulty** (%)					<0.01
None	29.9	21.5	21.5	3.9	
A little/some	41.8	40.0	24.3	19.6	
A lot/unable	28.4	38.5	54.2	76.5	
Difficulty with instrumental activities of daily living†† (%)					<0.01
None	67.5	60.3	38.3	7.8	
A little/some	16.5	17.8	20.6	11.8	
A lot/unable	16.0	21.9	41.1	80.4	

* *p* values were based on chi-squared tests for discrete variables and analysis of variance for continuous variables.

† Numbers in parentheses, standard deviation.

‡ MMSE, Mini-Mental State Examination.

§ The number of "definite" chronic conditions, including coronary artery disease (angina pectoris and/or myocardial infarction), congestive heart failure, degenerative disc disease, spinal stenosis, hip fracture, osteoporosis, osteoarthritis (of the knee, hip, or hand), rheumatoid arthritis, stroke, Parkinson's disease, pulmonary disease, diabetes mellitus, peripheral arterial disease, and cancer.

¶ "Definite" cases of six types of chronic disease: cardiovascular diseases (angina pectoris, congestive heart failure, myocardial infarction, peripheral artery disease), musculoskeletal diseases (hip fracture, osteoarthritis of the hip or knee), neurologic disorders (Parkinson's disease, stroke), pulmonary diseases, diabetes mellitus, and cancer.

\# Activities of daily living include bathing, dressing, eating, using the toilet, and getting into and out of bed.

** Difficulty in walking ¼ mile (0.4 km) and walking up 10 steps without stopping.

†† Instrumental activities of daily living include meal preparation, shopping for personal items, using a telephone, managing medications, and managing personal finances.

five frailty criteria were met. The resulting incidence data were grouped into three intervals defined by examinations 1, 3, 5, and 7. The goal was to assess the association between life space at baseline and 3-year cumulative incidence of frailty. Seventy-one women died during the 3-year follow-up period without prior observation of frailty onset (hereafter termed "frailty-free mortality"). We were concerned that, given the fact that frailty is a significant risk factor for mortality (1, 2), treating frailty-free mortality as a censoring event in a conventional Cox proportional hazards model might produce underestimation of the association between life space and frailty. The frailty-free mortality might be partially due to a missed opportunity to observe frailty before death as a result of discretely spaced data collection. To address this concern, we analyzed frailty-free mortality as a competing risk. When we define frailty incidence and frailty-free death as two mutually exclusive events, the problem fits into the conventional competing-risks framework (15).

In a competing-risks model, we analyzed incident frailty and frailty-free mortality as two separate outcomes. Specifically, we estimated and compared the cumulative incidence functions (16) for frailty and frailty-free mortality using the method of Gray (17). To adjust for other covariates, we implemented Fine and Gray's semiparametric proportional subdistributional hazards model (18).

For frailty-free death cases, the censoring time of frailty was set to the time of death. However, if the subject dropped out of the study (and was therefore missing data on frailty status) because she was too ill to participate or was in a hospital or nursing home, it was reasonable to assume that she was frail at the time of dropout. As a sensitivity analysis, we redefined 18 such cases as frailty incidence, with the onset time being the time at which the participant was last seen plus 6 months—the average gap until the next scheduled visit when the dropout reasons were ascertained.

Covariates were sequentially added to the model to evaluate associations of different levels of adjustment: model I included life-space indicators plus age, race, and education, and model II included the model I variables plus number of chronic diseases, MMSE score, depression, anxiety, personal mastery, self-reported ADL, IADL, and mobility difficulty. Income was not significant after adjustment for race and education; therefore, it was not included in the final model because of a high proportion of missing data. To assess overall model fit, we compared nonparametrically estimated cumulative incidence curves with those estimated from the proportional subdistributional hazards model. We assessed the proportional hazards assumption by visual inspection of the Schoenfeld-type residuals and by testing the significance of the interactions between the covariates in question and functions of time in the regression models; no evidence of departure from this assumption was found. All calculations were performed using R with the CMPRSK package (available at http://www.r-project.org).

RESULTS

A total of 599 women were not frail at baseline, though they were disabled. The degree of life-space constriction at baseline increased in a stepwise fashion with increasing age and with decreasing educational level, income, and MMSE score ($p < 0.01$; table 1). Women reporting greater levels of life-space constriction were also more likely to be African-American, depressed, and low in personal mastery. We also found that homebound women (i.e., the severely constricted) had a significantly higher prevalence of neurologic diseases (including stroke and Parkinson's disease) than women who were not homebound; those who never traveled outside the neighborhood (i.e., the severely or moderately constricted) were more likely to have diabetes than those who left the neighborhood. Furthermore, almost all homebound women reported some difficulty with mobility (96 percent) and IADL (92 percent); 74 percent reported difficulty with ADL. However, among women who left the neighborhood more than four times per week (i.e., were not constricted), 28 percent, 15 percent, and 16 percent reported a lot of difficulty with or being unable to carry out some mobility, ADL, and IADL tasks, respectively, and 42 percent, 46 percent, and 17 percent reported a little difficulty or some difficulty with these tasks, respectively. Life-space constriction was not significantly associated with living alone, number of chronic diseases, or anxiety.

TABLE 2. Crude total incidence rates of frailty and frailty-free mortality (per 100 person-years) over 3 years of follow-up, by level of life-space constriction at baseline, Women's Health and Aging Study I, 1992–1995

Incident event	Degree of life-space constriction			
	Not constricted ($n = 194$)	Slightly constricted ($n = 247$)	Moderately constricted ($n = 107$)	Severely constricted ($n = 51$)
Frailty	8.0	15.1	15.9	17.3
Frailty-free mortality	2.3	4.7	8.0	12.2

In longitudinal analyses, 186 women (31 percent) became frail and 71 (12 percent) died without prior observation of frailty onset over the 3-year follow-up period. Both the risk of incident frailty and frailty-free mortality increased with decreasing life space at baseline. The total crude incidence rate of frailty ranged from 8 per 100 person-years for the nonconstricted women to 17 per 100 person-years for the severely constricted women (table 2). The absolute risk of frailty was higher than that of frailty-free mortality for each level of life-space constriction. However, life space appeared to have stronger associations with frailty-free mortality than with frailty, as evidenced by the fivefold increase in the total incidence rate of frailty-free mortality, in contrast to the twofold increase for frailty when comparing the severely constricted group with the nonconstricted group (table 2).

Next, we formally tested the crude associations of life space with frailty and frailty-free mortality on the basis of nonparametrically estimated cumulative incidence curves. There was a stepwise positive association between greater life-space constriction at baseline and higher cumulative frailty incidence (figure 1). Differences among the top three most-constricted groups diminished by the end of year 3 as

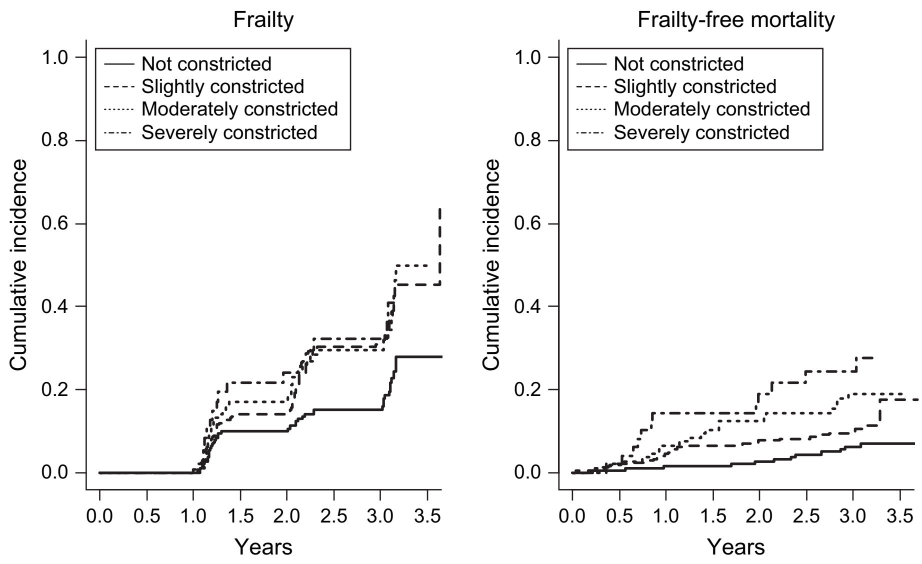

FIGURE 1. Cumulative incidence curves for frailty (left) and frailty-free mortality (right) according to baseline degree of life-space constriction among 599 women who were not frail at baseline, Women's Health and Aging Study I, 1992–1995. The figure shows stepwise positive associations between greater life space constriction at baseline and higher cumulative frailty incidence and frailty-free mortality.

the differences between these three groups and the nonconstricted group widened. The association with frailty-free mortality showed a different pattern of a steadily increasing, stepwise trend over time. The overall effect of life space was significant for both outcomes ($p < 0.01$).

Next we examined independent associations of life space with frailty and frailty-free mortality. After results were controlled for age, education, and race, women in the slightly constricted group were 1.7 times more likely to become frail than those in the nonconstricted group ($p < 0.01$); those with moderately or severely constricted life space were not significantly different from the nonconstricted group after covariate adjustment (table 3, model I.1). On the other hand, compared with the nonconstricted group, women with moderately and severely constricted life space experienced 2.6- and 3.5-fold increases in frailty-free mortality, respectively ($p < 0.05$; table 3, model I.2), while there was no significant association for the slightly constricted group. The results essentially remained unchanged after further controlling for number of chronic diseases, anxiety, personal mastery, depression, MMSE score, ADL, IADL, and mobility disability at baseline (table 3, model II). We also found that older age, lack of personal mastery, and baseline ADL disability were independently associated with significantly greater risk of incident frailty ($p < 0.01$), while older age and depressive symptoms were strong predictors of frailty-free mortality in these disabled women (table 3). The results remained essentially unchanged in the sensitivity analysis in which those lost to follow-up due to illness or nursing home admission were treated as if they were frail at the time of dropout.

Finally, to assess the degree to which intraindividual health characteristics might affect the relative impact of life-space constriction on frailty versus frailty-free mortality, we estimated the 3-year cumulative incidence of frailty and frailty-free death as a function of baseline age using model II in table 3, comparing two hypothetical cohorts of Caucasian women who had varying numbers of diseases and states of mental well-being but were otherwise comparable in terms of life space (slightly constricted), education (12th grade), MMSE score (27), and disability (presence of IADL and mobility disability only, without ADL disability). There was an accelerated increase in the risk of developing frailty or frailty-free death with aging (figure 2). A woman who at age 65 years reported a high level of personal mastery, no chronic diseases, and no depression or anxiety had an estimated probability of 0.10 of becoming frail within 3 years, which is twice as high as the probability (0.05) of frailty-free death with the same characteristics, and the difference widens with increasing age, with the probability of frailty estimated to be 0.32 versus 0.17 for frailty-free death at age 90 years. Thus, for women with relatively good health, frailty remains a primary risk at all ages. On the other hand, for a woman who has four diseases, a lack of personal mastery, anxiety, and depression, the risks for frailty and frailty-free death become more equitable (0.45 for frailty vs. 0.42 for frailty-free death at age 90 years).

DISCUSSION

Life space has been shown to have good construct and criterion validity for measuring severity of mobility limitation (7, 11, 19). Nonetheless, the value of the life-space instrument for predicting future health outcomes has not been well characterized. In this study, which to our knowledge was the first large population-based study to assess the relation between life space and future development of frailty,

TABLE 3. Independent association of life-space constriction at baseline with incident frailty and frailty-free mortality among 599 women who were not frail at baseline, Women's Health and Aging Study I, 1992–1995†

	Incident frailty				Frailty-free mortality			
	Model I.1		Model II.1		Model I.2		Model II.2	
	HR‡	95% CI‡	HR	95% CI	HR	95% CI	HR	95% CI
Degree of life-space constriction								
Not constricted§	1.0		1.0		1.0		1.0	
Slightly constricted	1.71**	1.18, 2.48	1.65*	1.13, 2.43	1.61	0.82, 3.17	1.53	0.77, 3.06
Moderately constricted	1.54	0.96, 2.48	1.44	0.90, 2.31	2.57*	1.23, 5.37	2.06	0.92, 4.58
Severely constricted	1.37	0.72, 2.60	0.98	0.51, 1.85	3.51**	1.52, 8.13	3.23**	1.35, 7.72
Age (per year)	1.06**	1.04, 1.08	1.05**	1.03, 1.08	1.06**	1.03, 1.09	1.05**	1.02, 1.09
Education (per year)	0.98	0.95, 1.02	0.97	0.93, 1.02	1.04	0.97, 1.11	1.07	0.99, 1.15
Black race	1.14	0.81, 1.62	1.26	0.87, 1.82	1.64	0.96, 2.80	1.51	0.85, 2.67
No. of chronic diseases¶			1.06	0.95, 1.19			1.18	0.98, 1.41
Anxiety			0.96	0.61, 1.50			1.01	0.51, 2.01
Personal mastery			0.65**	0.47, 0.89			1.48	0.86, 2.53
Geriatric Depression Scale score ≥14			0.82	0.49, 1.40			2.26*	1.04, 4.89
Mini-Mental State Examination score			1.02	0.95, 1.09			0.93	0.84, 1.02
Difficulty with activities of daily living#			1.75**	1.25, 2.44			0.78	0.43, 1.41
Difficulty with instrumental activities of daily living††			1.24	0.90, 1.71			1.43	0.83, 2.46
Mobility difficulty‡‡			1.36	0.92, 2.01			0.69	0.38, 1.26

* $p < 0.05$; ** $p < 0.01$.
† Results were obtained from Fine and Gray's semiparametric proportional subdistributional hazards model (18).
‡ HR, hazard ratio; CI, confidence interval.
§ Reference group.
¶ The number of "definite" chronic conditions, including coronary artery disease (angina pectoris and/or myocardial infarction), congestive heart failure, degenerative disc disease, spinal stenosis, hip fracture, osteoporosis, osteoarthritis (of the knee, hip, or hand), rheumatoid arthritis, stroke, Parkinson's disease, pulmonary disease, diabetes mellitus, peripheral arterial disease, and cancer.
# Activities of daily living include bathing, dressing, eating, using the toilet, and getting into and out of bed.
†† Instrumental activities of daily living include meal preparation, shopping for personal items, using a telephone, managing medications, and managing personal finances.
‡‡ Difficulty in walking ¼ mile (0.4 km) and walking up 10 steps without stopping.

both crude and adjusted analyses showed that women with a slightly constricted life space had a significantly higher risk of becoming frail as compared with the nonconstricted group. Notably, this risk was found in a cohort in which 97 percent of participants had already reported mobility disability, thus discriminating risk within this group. Obtaining empirical evidence of this association is the critical first step towards evaluating a broad conceptual framework about the etiology of frailty (figure 3). It is theorized that constriction of life space is a behavioral adaptation made in response to declining physiologic reserve and capacity with which to meet environmental challenges. The causes of this loss of physiologic reserve are likely to be multifactorial, including both environmental challenges (e.g., area deprivation) and intraindividual challenges (e.g., age-related physiologic changes). Constriction of life space could further lead to decreased physical activity and social engagement, accelerated deconditioning, and exacerbated decline in physiologic reserve, directly contributing—as these processes progress—to the development of clinical frailty and subsequent mortality. Future development of tools for the assessment of physiologic reserve and analysis of their relations to life space could help in delineating the hypothesized causal pathway.

In this study, severely constricted life space was not significantly associated with frailty after adjustment for potential confounders; instead, it was strongly predictive of frailty-free mortality. Our frailty measurements were taken only every 12 months, and it is possible that homebound women were more likely to develop frailty rapidly and die quickly. In this case, "frailty-free" death may in fact have been frailty-driven, leading to underestimation of frailty incidence if both frailty and death occurred within the same 12-month interval. The increasing evidence of accelerated frailty onset at older ages (20, 21) and its significant association with mortality (1, 2) provides empirical support for the above hypothesis. If this is true, our estimate of the effect of life-space constriction on the development of frailty is most likely to be conservative.

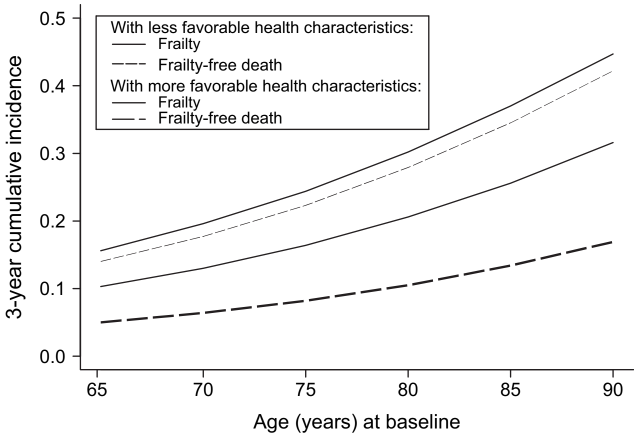

FIGURE 2. Predicted age-specific 3-year cumulative incidence of frailty and frailty-free death for two hypothetical cohorts of Caucasian women with slightly restricted life space, a 12th-grade level of education, a Mini-Mental Status Examination score of 27, and disability in mobility and instrumental activities of daily living. The two cohorts are free of disability in activities of daily living, but one has more favorable health characteristics (no chronic diseases, no anxiety, personal mastery, and no depression; represented by the thick lines) and the other has less favorable health characteristics (four chronic diseases, anxiety, lack of personal mastery, and depression; represented by the thin lines).

Almost all WHAS I women experienced some level of mobility difficulty. However, difficulty with mobility, IADL, and ADL tasks alone did not necessarily lead to a reduction in life space. Such discordance between functional capacity and actual performance has been reported in a number of other studies (9, 22–25). To explain the discrepancy, one could argue that some people may compensate for underlying functional decrements by adapting to a modified daily routine (e.g., the use of assistive devices) in order to maintain the same level of performance in real life (i.e., ''enacted function'') (9, 26). Although the exact reasons for this discrepancy remain unknown, we hypothesize that the employment of external (e.g., social support) and internal (e.g., using a cane) compensatory strategies (termed ''environmental supports'' and ''intraindividual supports,'' respectively, in figure 3) may help to minimize the impact of loss of physiologic reserve and thereby preserve life-space mobility. On the other hand, the ability to compensate effectively for functional limitations may itself be a function of physiologic reserve. It may be the interplay of functional limitations and functional reserve that determines actual function in the area of life-space diameter.

The implication of these findings is twofold. First, clinicians often regard persons who are homebound as being at elevated risk of poor outcomes. One interesting feature of our results is that it was not the women who were ''shut-ins'' who were at greatest risk of frailty but rather those women with slight life-space constriction. This is a potentially new

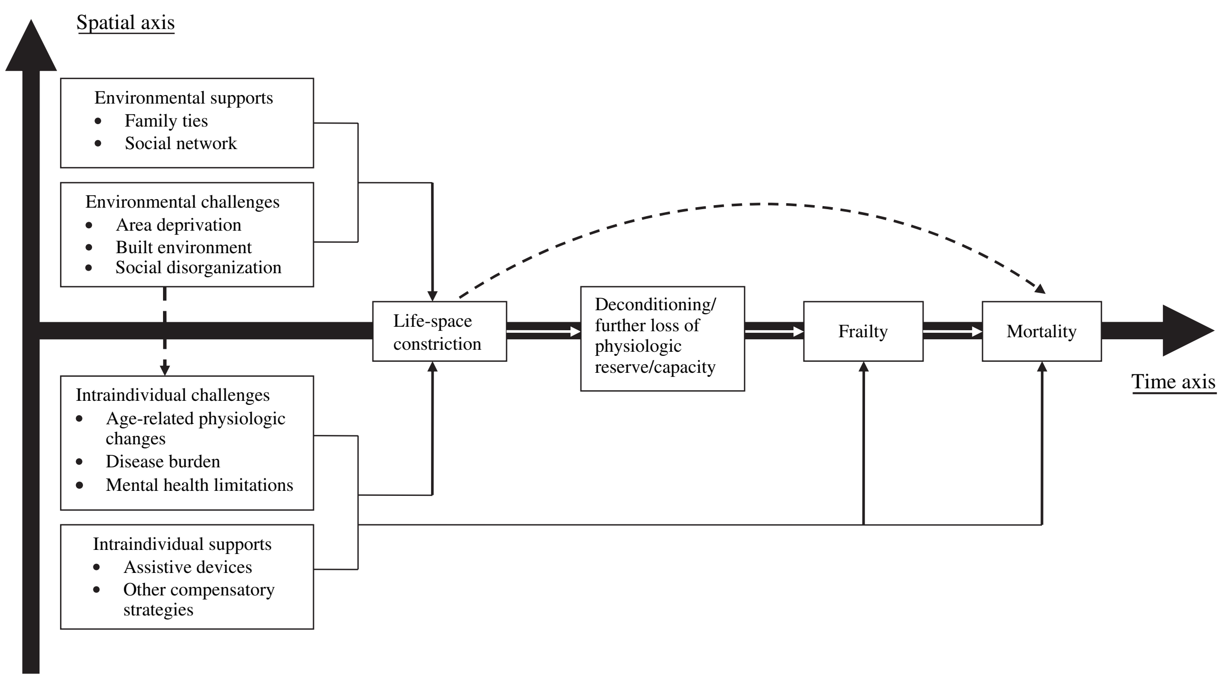

FIGURE 3. Theoretical model of the association of life space with the clinical syndrome of frailty. It is theorized that constriction of life space is a behavioral adaptation made in response to declining physiologic reserve and capacity with which to meet environmental challenges. Constriction of life space could further lead to decreased physical activity and social engagement, accelerated deconditioning, and exacerbated decline in physiologic reserve, directly contributing—as these processes progress—to the development of clinical frailty and subsequent mortality. The solid and dashed lines represent direct and indirect effects, respectively; arrows represent causal direction.

and intriguing target for clinical investigation as a screening tool. On the other hand, the strong association between homebound status and mortality suggests that by the time life-space constriction becomes moderate or severe, it may be too late to implement frailty interventions because of the high competing risk of mortality. Second, the results shown in figure 2 suggest that the severity of a person's underlying health status may modify outcomes associated with life-space constriction, in that the relative impacts of life-space constriction on frailty and frailty-free mortality could be dramatically different depending on other characteristics. Therefore, treatment decisions and planning for future health-care needs should be individualized, with each person's preferences and underlying health status being taken into account.

In this study, we applied state-of-the-art statistical methods to dealing with competing mortality, an issue that is commonly encountered in gerontologic research (27). Had we treated frailty-free mortality as a censored observation, the effect of life space on frailty would have been underappreciated. Thus, statistical reasoning is more important than ever for studying the etiology of a complex syndrome like frailty in a highly vulnerable population.

One limitation of the study is that our analyses were restricted to a cohort of disabled women living in the community. Therefore, the results cannot be generalized to men or to less disabled women. In this study, we found that 37 percent of the homebound and 26 percent of the moderately constricted women had frailty status censored for reasons other than mortality before the end of the 3-year follow-up period, as compared with 15 percent and 18 percent for the slighted constricted and nonconstricted women, respectively. Given that life-space constriction was associated with increased risk of frailty, the observed associations between moderately and severely constricted life space and incident frailty are most likely to be conservative because of the selective drop-out. Another limitation is that we only had a partial subset of questions from the larger life-space instrument developed by Stalvey et al. (11). Although this shortened version of the life-space scale might have limited sensitivity for detecting small changes in life space over time (7), the simplicity of our measure makes it a realistic screening tool for use in clinical and research settings.

In summary, this study provides the first evidence that slightly constricted life space may serve as an important marker and/or risk factor for the development of frailty, whereas severely constricted life space may indicate a high risk of mortality. Because this measure has sufficient sensitivity to discern risk when subjects already report mobility difficulty, it offers a useful screening tool and potential etiologic insights. These findings provide a scientific rationale for future investigation of potential risk factors for life-space constriction and the causal pathway between life-space changes and frailty within the proposed theoretical framework.

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