Cognitive Aging and Rate of Hospitalization in an Urban Population of Older People

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Background. The association of age-related cognitive change with hospitalization is not well understood.

Methods. At 3-year intervals for a mean of 8.7 years, 2,273 older residents of a geographically defined urban community underwent cognitive testing from which a global measure was derived. Hospitalization data were obtained from Part A Medicare beneficiary records. The association of level of cognitive function and rate of cognitive decline in each 3-year interval with subsequent rate of hospitalization was assessed using mixed-effects count regression models.

Results. There were 9,091 hospitalizations involving 1,810 of the 2,273 individuals in the cohort (79.6%). Rate of hospitalization increased by 9.7% (95% confidence interval [CI]: 7.2, 12.3) with each additional year; by 32.7% (95% CI: 26.8, 38.0) for each 1 point lower on the global cognitive measure at the beginning of an observation interval; and by 24.3% (95% CI: 16.6, 32.6) for each 1-point decrease in the global cognitive measure during the previous observation period. These associations persisted after adjustment for comorbidities and exclusion of those with a Mini-Mental State Examination score less than 26.

Conclusion. Individual differences in trajectories of cognitive aging are associated with subsequent risk of hospitalization.

Key Words: Cognitive aging—Epidemiology—Hospital related—Public health.

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Epidemiological research on those aged 65 years or older suggests that approximately 10% meet criteria for dementia (1), another 20% have mild cognitive impairment (2,3), and another 10%–20% have pathological changes in the brain, suggesting increased risk of cognitive decline (4,5). These estimates suggest that mild cognitive dysfunction is substantially more common in old age than dementia.

With the aging of the U.S. population, the number of individuals with age-related cognitive dysfunction is expected to increase in the next few decades (6), underscoring the importance of securely understanding the consequences of this dysfunction. However, information on the consequences of impaired cognition mainly comes from research on persons with dementia. These studies have associated late-life dementia with a range of adverse health consequences, including increased cognitive decline (7), disability (8), and death (9). Although milder late-life cognitive dysfunction is more common than dementia, its consequences have not been as extensively studied (7,9), limiting what is known about this large and growing segment of the population.

In the present study, we examine another possible consequence of late-life cognitive dysfunction, hospitalization. Dementia has been associated with an increased likelihood of hospitalization in both prospective cohort (10) and retrospective claims-based (11) studies. Most research on older persons without dementia has not suggested an association between cognitive functioning and hospitalization (12–15). However, only two of the latter studies directly assessed change in cognitive function (rather than inferring it from between-person differences in level of cognitive function), and the opportunity to observe change in these studies may have been limited by the relatively brief observation periods of 3–4 years (13,14).

We used data from the Chicago Health and Aging Project to test the hypothesis that lower level of cognitive function and faster rate of cognitive decline predict higher subsequent rate of hospitalization. Participants are 2,273 residents of a
geographically defined community in Chicago. Cognitive function was assessed with a battery of brief tests at 3-year intervals for a mean of 8.7 years, and Medicare records of hospitalization were obtained. We used mixed-effects count regression models to assess the hypothesized association of level of cognitive function and rate of cognitive change with subsequent rate of hospitalization.

**METHODS**

**Participants**

From October 1993 to April 1997, a geographically defined community in Chicago was censused as part of the Chicago Health and Aging Project (16). Persons aged 65 years or older were invited to participate in an in-home interview that included brief cognitive testing. The interview was subsequently repeated at intervals of approximately 3 years with six interview waves completed at the time of analyses.

Eligibility for analyses required Medicare data, to assess hospitalization, and a minimum of three complete interviews, to assess baseline cognition and cognitive change. To date, 10,459 individuals have completed the baseline interview. Medicare data were not available for 3,843 participants (enrolled in a health maintenance organization [n = 1,688]; age <65 years at baseline [n = 146]; Medicare data available for some but not all of the observation period [n = 763]; Medicare number did not match data from the Centers for Medicare and Medicaid Services [n = 690]; Medicare records not yet requested [n = 556]). Compared with those without Medicare data, the 6,616 persons with Medicare data were younger, more educated, less likely to be female and black, and had a better global cognitive score at baseline (Supplementary Table 1). Of the 6,616 persons with Medicare data, 1,651 died within 6 years of baseline, and 1,503 had been in the study less than 6 years. This left 3,462 persons potentially eligible individuals of whom 2,276 (65.7%) completed three or more interviews. We excluded three persons with missing data on education, leaving 2,273 persons in the analytic group. Compared with the 4,343 persons who are not included in analyses, those in the analytic group were younger, more educated, less likely to be male and black, and had a better global cognitive score at baseline (Supplementary Table 2). The analytic group had a mean age at baseline of 71.9 (SD = 5.4) and a mean of 13.0 years of education (SD = 3.5); 60.7% were women and 55.1% were black. The mean observation time was 8.7 years (SD = 2.9).

Assessment of Cognitive Function

The test battery was designed to provide a psychometrically sound measure of global cognition while being brief and acceptable to participants and allowing comparison with other cognitive aging research. Four brief tests were administered at each interview: immediate and delayed recall of 12 ideas in the East Boston Story; a modified Symbol Digit Modalities Test, a measure of perceptual speed, one component of executive function; and the Mini-Mental State Examination, a 30-item measure of global cognition. To minimize measurement error and because, in a previous factor analysis, all four measures loaded on a single factor that accounted for more than 70% of the variance on the individual tests (17), we used a composite measure of global cognition based on all four tests as the primary outcome. Raw scores on each test were converted to z scores, using the mean and standard deviation of the population at baseline, and averaged to yield the composite score. Secondary analyses were conducted with the Symbol Digit Modalities Test and a composite of immediate and delayed recall (18,19), to see if results varied by cognitive domain, and with the Mini-Mental State Examination, to place the results in a familiar clinical context. The reliability of the measures was assessed in a stratified random sample of 685 participants who were retested a mean of 7.7 months (SD = 8.0) after the baseline interview (16). The test–retest correlations were 0.86 for the global cognitive score, 0.89 for the Symbol Digit Modalities Test, 0.72 for the composite of immediate and delayed recall, and 0.89 for the Mini-Mental State Examination (each p < .001), indicating adequate reliability. These same cognitive measures have previously been shown to decline with age (20,21) and predict mortality (22), supporting their validity as measures of late life cognitive ability.

**Assessment of Hospitalization**

We obtained data on hospital use from January 1993 through December 2007 from Part A Medicare beneficiary records.

**Assessment of Other Covariates**

Each interview included assessment of four health indicators with the potential to affect the association of cognition with hospitalization. Depressive symptoms were assessed with a 10-item form of the Center for Epidemiological Studies Depression Scale (23). The score is the number of symptoms experienced in the last week. Disability was assessed with the Katz scale (24). The score is the number of six basic activities of daily living for which assistance is required. Lower extremity physical function was assessed with three performance-based measures: time to complete an 8-foot walk, time to perform five chair stands, and duration of a full tandem stand (to a maximum of 10 seconds). The time for each task was divided into quintiles with an additional category for those unable to complete the task, and scores (0–5) were summed to create a composite measure of lower extremity function (25). Structured questions addressed six common medical conditions associated with functional and cognitive impairment: hypertension (present...
in 48.5% at baseline), diabetes (5.7%), stroke (6.3%), heart disease (11.5%), cancer (19.4%), and broken hip (2.1%). The number of conditions at baseline was used as an indicator of chronic illness (26).

Statistical Analysis

Each person’s study time was divided into the approximately 3-year intervals between longitudinal cognitive assessments. We used mixed-effects count regression models (27) to assess rate of hospitalization across intervals and test whether cognitive level or decline in one interval predicted hospitalization in the next interval. We used a lagged negative binomial regression model with a log link function for mean and over-dispersed variance function. Random effects were included for the intercept to allow for individual differences in initial level of hospitalization rate. Each model included a term for time (in years since first observation) and time-varying terms for prior cognitive level and decline. Terms for age, sex, race, education, and their interactions with time were included to adjust for their association with initial level of hospitalization rate and change in the rate over time. Subsequent models tested for an interaction between cognitive level and decline; used different cognitive measures; included time-varying terms to adjust for prior level of and rate of change in medical conditions, disability, lower extremity physical function, and depressive symptoms; and included interaction terms to test whether demographic variables modified the relation of the cognitive variables to subsequent hospitalization rate, with separate models for age, sex, race, and education. We also conducted sensitivity analyses: the initial model was repeated, excluding persons with cognitive impairment; we modeled death and hospitalization together in a shared parameter model to determine whether exclusions were mortality affected results; and we constructed a mixed-effects model to determine whether selective exclusions were related to cognitive functioning.

Results

During a mean of 8.7 years of observation (SD = 2.9), 1,810 of the 2,273 participants were hospitalized 9,091 times, a mean annual rate of 460 admissions per 1,000 individuals, which is comparable to national data (28,29). On average, there were 4.0 hospitalizations per individual for the full study period (SD = 5.0) and 1.2 hospitalizations per individual for each 3-year observation interval (SD = 2.0).

Cognitive Function and Hospitalization

We constructed a series of mixed-effects count regression models to characterize rate of hospitalization over time and to test for the hypothesized association with cognitive functioning. In these models, the outcome was the rate of hospitalization in each 3-year interval between longitudinal cognitive assessments. The key predictors in primary analyses were time-varying terms for level of global cognition (mean = 0.39, SD = 0.62, skewness = −1.3) and rate of global cognitive decline (mean = 0.11, SD = 0.52, skewness = 1.0) in the immediately preceding 3-year interval.

In the initial analysis (Table 1), the rate of hospitalization increased by 9.7% per year, as shown by the term for time. Rate of hospitalization increased by 32.7% (ie, 1 minus the rate for prior global cognitive level) for each 1 point lower on the global cognitive score in the prior observation period and by 24.3% for each 1-point decrease in the global cognitive score in the prior observation period (Table 1). In a subsequent analysis, there was no interaction between cognitive level and decline (estimate = −0.041, SE = 0.036, p = .266).

To visualize these effects, we plotted the predicted 10-year trajectory of rate of hospitalization for typical participants with moderately low (25th percentile, dotted line) or high (75th percentile, solid line) prior levels of cognitive function (Figure 1, left side) and moderately rapid (25th percentile, dotted line) or slow (75th percentile, solid line) prior rates of cognitive decline (Figure 1, upper right). To place these effects in context, the cognitive level difference is equivalent

<table>
<thead>
<tr>
<th>Model Term</th>
<th>Estimate</th>
<th>SE</th>
<th>p</th>
<th>Rate†</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (y)</td>
<td>0.093</td>
<td>0.012</td>
<td>&lt;.001</td>
<td>1.097</td>
<td>1.072, 1.123</td>
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<tr>
<td>Baseline age (y)</td>
<td>0.021</td>
<td>0.007</td>
<td>.01</td>
<td>1.021</td>
<td>1.008, 1.034</td>
</tr>
<tr>
<td>Baseline age × Time</td>
<td>0.002</td>
<td>0.001</td>
<td>.068</td>
<td>1.002</td>
<td>1.000, 1.005</td>
</tr>
<tr>
<td>Sex</td>
<td>−0.008</td>
<td>0.069</td>
<td>.907</td>
<td>0.992</td>
<td>0.886, 1.136</td>
</tr>
<tr>
<td>Sex × Time</td>
<td>0.016</td>
<td>0.014</td>
<td>.230</td>
<td>1.016</td>
<td>0.990, 1.044</td>
</tr>
<tr>
<td>Race</td>
<td>−0.264</td>
<td>0.077</td>
<td>&lt;.001</td>
<td>0.768</td>
<td>0.660, 0.894</td>
</tr>
<tr>
<td>Race × Time</td>
<td>0.040</td>
<td>0.015</td>
<td>.006</td>
<td>1.041</td>
<td>1.012, 1.071</td>
</tr>
<tr>
<td>Education (y)</td>
<td>−0.003</td>
<td>0.011</td>
<td>.758</td>
<td>0.997</td>
<td>0.976, 1.018</td>
</tr>
<tr>
<td>Education × Time</td>
<td>−0.006</td>
<td>0.002</td>
<td>.005</td>
<td>0.994</td>
<td>0.990, 0.998</td>
</tr>
<tr>
<td>Prior global cognitive level</td>
<td>−0.395</td>
<td>0.043</td>
<td>&lt;.001</td>
<td>0.673</td>
<td>0.620, 0.732</td>
</tr>
<tr>
<td>Prior global cognitive decline</td>
<td>0.218</td>
<td>0.033</td>
<td>&lt;.001</td>
<td>1.243</td>
<td>1.166, 1.326</td>
</tr>
</tbody>
</table>

Notes: CI = confidence interval; SE = standard error.
*Estimated from a mixed-effects count regression model.
†Results show the effect of a 1-unit increase in the model term on annual hospitalization rate.
to being more than 10 years older, and the decline difference is equivalent to being more than 5 years older. The figures suggest a dose–response type relationship between both cognitive level and rate of change on the one hand and subsequent rate of hospitalization on the other hand.

To see if some cognitive domains contributed to the association with hospitalization more than others, we conducted separate analyses using the measures of executive function and episodic memory instead of the global cognitive measure. In these analyses (Table 2), lower prior level and more rapid decline of both executive function and episodic memory were robustly associated with increased rate of hospitalization though Figure 2 suggests that the association is slightly stronger for executive function (upper panel) than episodic memory (middle panel).

To assist clinical interpretation of the findings, we conducted a final analysis with the widely used Mini-Mental State Examination (lower panel of Figure 2). Rate of hospitalization increased by 3% for each point lower on the Mini-Mental State Examination in the prior period (95% CI: 1.4, 4.5) and by 2.7% for each point increase in rate of Mini-Mental State Examination decline in the prior period (95% CI: 1.4, 4.0).

Sensitivity Analyses

To determine whether results depended on individuals with severe cognitive impairment, we repeated the original model excluding data from intervals that began with a Mini-Mental State Examination score below cutpoints ranging from 20 to 26 (Supplementary Table 3). The associations of cognitive level and decline with subsequent hospitalization were virtually unchanged in these analyses.

We examined the impact of missing data in two separate analyses. First, in a mixed-effects model, exclusion for lacking Medicare data was not associated with cognitive decline (estimate = −0.005, SE = 0.003, p = .079) but exclusion for insufficient longitudinal cognitive data was (estimate = −0.010, SE = 0.003, p < .001), indicating better cognitive health in the analytic group compared

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Table 2. Associations of Executive Function and Episodic Memory With Subsequent Rate of Hospitalization

<table>
<thead>
<tr>
<th>Model Term</th>
<th>Estimate</th>
<th>SE</th>
<th>p</th>
<th>Rate†</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (y)</td>
<td>0.057</td>
<td>0.013</td>
<td>&lt;.001</td>
<td>1.059</td>
<td>1.032, 1.086</td>
</tr>
<tr>
<td>Prior executive function level</td>
<td>−0.247</td>
<td>0.043</td>
<td>&lt;.001</td>
<td>0.781</td>
<td>0.718, 0.850</td>
</tr>
<tr>
<td>Prior executive function decline</td>
<td>0.182</td>
<td>0.037</td>
<td>&lt;.001</td>
<td>1.200</td>
<td>1.115, 1.179</td>
</tr>
<tr>
<td>Time (y)</td>
<td>0.059</td>
<td>0.013</td>
<td>&lt;.001</td>
<td>1.066</td>
<td>1.034, 1.087</td>
</tr>
<tr>
<td>Prior episodic memory level</td>
<td>−0.168</td>
<td>0.039</td>
<td>&lt;.001</td>
<td>0.846</td>
<td>0.784, 0.912</td>
</tr>
<tr>
<td>Prior episodic memory decline</td>
<td>0.085</td>
<td>0.029</td>
<td>.003</td>
<td>1.089</td>
<td>1.029, 1.153</td>
</tr>
</tbody>
</table>

Notes: CI = confidence interval; SE = standard error.
*Estimated from 2 separate mixed-effects count regression models adjusted for age at baseline, sex, race, years of education, medical conditions, disability, lower extremity physical function, and depressive symptoms.
†Results show the effect of a 1-unit increase in the model term on annual hospitalization rate.

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Figure 1. Predicted rates of hospitalization in participants with moderately low (25th percentile, dotted line) or high (75th percentile, solid line) prior cognitive level (left side) and moderately fast (25th percentile, dotted line) or slow (75th percentile, solid line) prior cognitive decline (right side), based on a mixed-effects count regression model adjusted for age at baseline, sex, race, and years of education.

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Figure 2. Predicted rates of hospitalization in participants with moderately low (25th percentile, dotted line) or high (75th percentile, solid line) prior cognitive level (left side) and moderately fast (25th percentile, dotted line) or slow (75th percentile, solid line) prior cognitive decline, based on three separate mixed-effects count regression models adjusted for age at baseline, sex, race, and years of education, using an executive function measure (upper panel), an episodic memory measure (middle panel), and the Mini-Mental State Examination (lower panel).
with those not included. Second, to assess whether attrition due to death affected results, we simultaneously modeled hospitalization and death. The associations of prior cognitive level (estimate = −0.387, SE = 0.042, p < .001) and decline (estimate = 0.230, SE = 0.033, p < .001) were comparable to the original analysis, suggesting that death did not bias the association of cognitive functioning with hospitalization.

**Secondary Analyses**

Cognitive functioning in old age has been associated with indicators of health and well-being that might account for cognition’s association with risk of hospitalization, including general physical health (30), disability (8), gait (31), and depressive symptoms (32). Therefore, we repeated the model with time-varying terms for prior level and prior rate of change in measures of common medical conditions, disability, lower extremity physical function, and depressive symptoms. In this analysis, both prior level of global cognition (estimate = −0.273, SE = 0.050, p < .001) and more rapid global cognitive decline (estimate = 0.160, SE = 0.040, p < .001) continued to be robustly associated with subsequent rate of hospitalization though the strength of the associations was slightly reduced.

Because there has been little prior research on the association of cognition with hospitalization, we examined whether the association varied along demographic lines. In an initial analysis, there was an interaction of age with prior level of cognition (estimate = 0.016, SE = 0.006, p = .012), indicating that the negative association of prior cognition with risk of hospitalization was weaker at older ages compared with younger ages. Age did not interact with cognitive decline (estimate = −0.012, SE = 0.007, p = .070), however, and in subsequent analyses, there were no interactions involving sex, race, or education.

**DISCUSSION**

In a longitudinal study of more than 2,000 older residents of an urban community, we assessed cognitive function and obtained Medicare records of hospitalization. During a mean of 8.7 years of observation, both lower level of cognitive function and more rapid rate of cognitive decline were associated with a subsequent increase in rate of hospitalization even after controlling for multiple indices of health and well-being. The results suggest that loss of cognition leads to an increased rate of hospitalization.

Prior research on the relation of level of cognitive function to subsequent risk of hospitalization has been mostly null. In a selected group of older patients, score on a brief cognitive test was associated with an increased risk of being hospitalized at least once in the following year but not with the total number of hospitalizations during the year (12). In two population-based studies of older persons without dementia at enrollment, initial cognitive score did not predict hospitalization in the following 2–3 years (13,14), and a retrospective population-based study found no increase in hospitalization in the year prior to the clinical diagnosis of Alzheimer’s disease (15). We are aware of two population-based studies with data on change in cognitive function and hospitalization. In one, 3-year decline on a brief mental status test was related to hospitalization during the same period (13), supporting the idea that cognitive decline is related to hospitalization but not clarifying whether it preceded hospitalization. The other study had a median of 4.0 years of observation before hospitalization but did not observe an association between decline and hospitalization in older health maintenance organization members without dementia at baseline (14).

The bases of the association of cognitive impairment and decline with hospitalization are uncertain. Results were unchanged when data from the most cognitively impaired persons were eliminated, suggesting that the association reflects individual differences across a wide spectrum of cognitive aging rather than a subset of individuals with severe cognitive impairment. The association is probably partly due to cognitive dysfunction being an early sign of conditions that may subsequently require hospitalization (eg, Parkinson’s disease). The association persisted after adjustment for multiple health indicators, however, suggesting that loss of cognitive skills also directly influences the likelihood of hospitalization, underscoring the fact that self-management of health care in old age is a cognitively demanding task even for persons without manifest cognitive impairment. Lower level of cognitive function has been associated with lower level of health literacy (33) and key health-related behaviors such as medication adherence (34), maintaining oral hygiene (35), and avoiding serious accidents (36). Thus, loss of cognitive skills, perhaps particularly executive functions, likely diminishes the self-care component of health care, thereby increasing the likelihood of comorbid medical conditions developing or worsening. In addition, cognitive dysfunction may affect the presentation of medical conditions in ways that increase the likelihood of hospitalization (eg, inadequate clinical history).

Previous work suggests that hospitalization predicts increased risk of cognitive impairment (14) and decline (19), and the present results indicate that cognitive level and decline also predict hospitalization. These two sets of results suggest a vicious circle involving cognition and hospitalization in old age. That is, those who are cognitively impaired are at increased risk of being hospitalized, thereby increasing subsequent likelihood of cognitive decline. Reducing this public health problem is likely to require interventions that somehow reduce the association of cognitive impairment with subsequent hospitalization. Part of the solution may be to target health self-care skills with educational programs to enhance them (37) and outreach programs to supplement them (38), but it is likely that more comprehensive approaches will be needed.
Strengths and limitations of these data should be noted.
Cognition was assessed at regular intervals with psychometrically sound measures for a mean of more than 8 years, enhancing our ability to link components of each person’s cognitive trajectory with subsequent rate of hospitalization. Participants were systematically recruited from a geographically defined area, making it likely that the results accurately reflect this Midwestern urban population. However, because patterns of health services utilization vary from region to region, the results may not generalize to other populations. Another limitation is that persons had to have Medicare data and survive at least 6 years to be included in analyses, and this may have affected the observed association of cognition with hospitalization. In addition, analyses did not take into account why individuals were hospitalized or whether psychosocial factors affected the decisions.

**Supplementary Material**
Supplementary material can be found at: [http://biomedgerontology.oxfordjournals.org/](http://biomedgerontology.oxfordjournals.org/)

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