Journal of Gerontology: PSYCHOLOGICAL SCIENCES
1999, Vol. 54B, No. 5, P273–P282

Cognitive and Sociodemographic Risk Factors for Mortality in the Seattle Longitudinal Study

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The relationship between cognitive function and survivorship was examined in a community-dwelling sample. Survival analysis was used to examine how level and change in intellectual functioning, verbal memory, perceptual speed, and psychomotor speed were related to mortality in a sample of 601 individuals who subsequently died (decedents; n *= 342 men;* n *= 259 women;* M *= 73.81 years of age) and a control group of 609 survivors (*n *= 296 men;* n *= 313 women;* M *= 71.96). The sample of survivors was selected to be of similar age and to have a similar level of education as the decedents. Individuals in the lowest 25th percentile of performance (crystallized abilities, visualization abilities, verbal memory, and perceptual and psychomotor speed) had a significant risk for subsequent mortality compared to individuals in the highest 25th percentile. However, after adjusting for demographic variables and psychomotor speed, only perceptual speed remained a significant risk factor for mortality. Significant 7-year declines (lowest 25th percentile) in measurements of Verbal Meaning, Spatial Ability, Reasoning Ability, and Psychomotor Speed were risk factors for subsequent mortality relative to those who had the least amount of decline. The relationship between mortality and cognitive function tended to be a specific rather than a pervasive phenomenon, even after adjusting for sociodemographic factors and psychomotor speed. Decrease in cognitive performance tended to be a better predictor of subsequent mortality than was the level of cognitive performance.*

LOWER cognitive performance in adults has been found to be associated with earlier mortality in several studies (Bosworth & Schaie, 1999; Deeg, Hofman, & Van Zonneveld, 1990; Liu, LaCroix, White, Kittner, & Wolf, 1990; Maier & Smith, 1999; see Berg, 1996, for review). Despite evidence of a general association between cognitive function and mortality, consistent findings are still lacking as to whether this association is pervasive across all abilities; is affected by gender, education, and age; and is maintained across cross-sectional and longitudinal analyses of cognitive performance. These issues were studied in a sample of community-dwelling adults using a large battery of cognitive measures.

The possible mechanisms underlying the relationship between cognitive performance and subsequent mortality have been the subject of much speculation in the literature. Swan, Carmelli, and LaRue (1995) suggest that theories of the mechanism fall into three main categories: brain damage, general systematic decline, and diseases. The first category suggests that changes occurring at a neurological level may explain the association between cognition and mortality (Ivy, McLeod, Petit, & Markus, 1992). In addition, Ivy and colleagues (1992) argue that an age-related decrease in the number of neurons reduces the number of basic elements that the organism can use to process, acquire, and store information. Because psychological tests assess the integrity and efficiency of the central nervous system, these tasks may reflect the pathological condition of brain function (Muscovith & Winocur, 1992).

The second class of theories suggests that, although there are decrements in cognitive function, the relationship between cognition and mortality may be a marker of a general global decline. The possibility remains that a lowered level of cognitive function plays an indirect role in impacting health. For example, intact memory is necessary to remember to take required medications, keep health care appointments, or practice sound preventive care and proper nutrition. Similarly, perceptual speed may reflect primary aging of the central nervous system (Birren, 1965; Birren, Woods, & Williams, 1979; Swan et al., 1995), and if slowing is a marker for central nervous system aging, then aging of the central nervous system might be expected to reduce adaptive capacity in a general way, thereby increasing susceptibility to death from a variety of causes.

The third class of theories suggests that low performance is an indicator of a general or specific organ disturbance produced by diseases not directly involved with the brain, such as metabolic, toxic, or neurochemical dysfunctions or a systemic disease (Steuer & Jarvik, 1981; Swan et al., 1995). Cardiovascular disease is an example of a systemic disease that seems to affect the nervous system and higher psychological functions (Hertzog, Schaie, & Gribbin, 1978).

Despite the possible mechanisms that may explain the relationship between cognitive performance and mortality, it has been difficult to determine whether the relationship is pervasive or specific. Past research has often been confined to a single measure of cognitive ability (Berg & Jeppson, 1991; Bruce, Hoff, Jacobs, & Leaf, 1995; Deeg et al., 1990; Johansson & Berg, 1989; Swan et al., 1995) or to relatively few abilities (White & Cunningham, 1988) in predicting mortality.

An additional problem is that some of the previous studies failed to include women (e.g., Berkowitz, 1965; Kleemeier, 1962; Swan et al., 1995) or to control for gender differences in life expectancies (Palmore & Cleveland, 1976; Riegel & Riegel, 1972; Steuer, LaRue, Blum, & Jarvik, 1981). Excluding women from studies of the relationship between cognition and mortality is problematic for two reasons. First, there are systematic gender differences in cognitive performance. On the Primary Mental Abilities (PMA) test, for example, men do better on Spatial Orientation and Numerical Ability, but women excel on Inductive Reasoning, Verbal Meaning, and Word Fluency (Schaie, 1983, 1996). Second, there are also systematic gender differences in longevity (U.S. DHHS, 1993). Because gender is confounded with both mortality and cognitive function, gender should be considered when studying the relationship between the two.

There also has been disagreement as to which age groups are most likely to be affected by the association between cognitive function and mortality. For example, Deeg and colleagues (1990) found that the rate of decline of cognitive function was strongly associated with subsequent survival time for those who were at least aged 70 but not for a younger age group (aged 65–69). In contrast, White and Cunningham (1988) reported that in their cross-sectional study, the prediction of mortality based on verbal ability was more accurate in adults aged 70 or younger. These authors suggest that death in older individuals is generally believed to be more random than in the "young-old." Perls, Morris, Ooi, and Lipsitz (1993), using longitudinal data, found results suggesting that individuals who survived into advanced age may be more of a select cohort who escaped the development of neurological disease.

Besides considering the effects of gender and age, education must be considered when examining the relationship between cognition and mortality. Educational history has been one of the most consistent predictors of cognitive decline, with higher levels of education being associated with greater maintenance of cognitive performance (Evans et al., 1993). Studies have also shown that low education is associated with an excess prevalence of chronic diseases, including cardiac, pulmonary, gastrointestinal, musculoskeletal, and psychiatric disorders (Pincus, Callahan, & Burkhauser, 1987).

Previous studies have related level of performance to mortality but have not always examined whether magnitude of decline is predictive of death (Swan et al., 1995; White & Cunningham, 1988). Disagreements over the relationship between mortality and cognition may be partially explained by comparing cross-sectional and longitudinal findings. Although there is some evidence to suggest that low levels of cognitive function may represent increased risks of mortality (Aronson et al., 1991; Bruce et al., 1995; Liu et al., 1990), reports of longitudinal studies relating decline in cognitive function to survival in samples of the general population are inconsistent. Some investigators have suggested that there is a "critical" decline in cognitive function that separates survivors from decedents (Berg, 1987; Deeg et al., 1990). Other investigators have not found any relation between decline in cognitive function and survival (Botwinick, West, & Storandt, 1978; Bruce et al., 1995).

An additional problem with past studies is that they have not always considered the role of psychomotor speed in partially explaining the relationship between cognition and mortality. There is growing evidence that psychomotor speed, a measure of perceptual speed, is an important contributor to the decline in cognitive performance that occurs in many tasks with increased age (Salthouse, 1985, 1993a). Health status is one possible source, or mediating factor, that may explain the association between age and speed. For example, findings have indicated that decline in psychomotor speed is accelerated with the presence of cardiovascular disease (Hertzog et al., 1978; Light, 1978). Because psychomotor speed is likely to be related somewhat to both health and general cognitive decline, it is likely to influence the relationship between various cognitive measures and subsequent mortality.

The Seattle Longitudinal Study provides an opportunity to explore the relation of level and decline for various mental abilities (i.e., Word Fluency, Verbal Meaning, Numerical Ability, Spatial Orientation, Inductive Reasoning, Verbal Memory, Perceptual Speed, and Psychomotor Speed) to mortality in a large community-dwelling sample. The Word Fluency, Verbal Meaning, and Numerical Ability subtests of the Primary Mental Ability test measure crystallized abilities, whereas Spatial Orientation measures visualization ability, and Inductive Reasoning measures fluid ability. Crystallized abilities involve the formation of skills and strategies that people have acquired through experience, and fluid abilities indicate the ability to deal with novel problems and to perceive and discriminate relations. Visualization ability involves perceiving and thinking with visual patterns and spatial configurations (Cattell, 1963; Schaie, 1996; Woodcock, 1990). The Identical Pictures, Finding A's Task, and Number Comparison are measures of perceptual speed (Schaie, Dutta, & Willis, 1991; Schaie, Willis, Hertzog, & Schulenberg, 1987), and Immediate Recall and Delayed Recall measure verbal memory (Schaie, 1983; 1996). Crystallized intelligence remains relatively stable, whereas fluid intelligence, visualization ability, and perceptual speed decline steadily with increased age (Horn, 1982; Schaie, 1983; 1996). The rate of decline of memory performance is dependent upon the type of memory task (Craik, Byrd, & Swanson, 1987). However, memory performance generally declines over the life span, especially when measured by tasks requiring recall, such as the present measures of verbal memory, rather than recognition.

Three major research questions were investigated in this study. First, is there a relationship between cognitive function and risk of mortality? It is hypothesized that those individuals who exhibit low levels of cognitive function at last measurement will be at an increased risk of early mortality after considering gender, level of education, and age. Based upon prior research, we hypothesized that Psychomotor Speed, an indicator of perceptual speed, would more likely be related to mortality than other abilities. Second, does the relationship between level of cognitive function at last measurement and the risk of mortality differ among age groups? There have been conflicting findings about whether the relationship between cognition and mortality varies across age groups. Third, does the magnitude of cognitive decline over individuals' last two measurements (7-year decline) predict mortality? Those individuals who experience a significant decline are hypothesized to be at an increased risk of mortality.

METHODS

Participants

The Seattle Longitudinal Study is a cohort-sequential study that has collected data on more than 5,000 participants between the ages of 22 and 95. Participants were selected randomly from within gender and age/cohort groups from membership in a large health maintenance organization (HMO) in the Seattle, Washington, area. The sampling frame was a community-dwelling population representing a wide range of occupational, educational, and economic backgrounds (Schaie, 1996). By comparison with area census figures, the sample underrepresents the lowest socioeconomic segment of the population but has reasonable representative characteristics for at least the upper 75% range of the socioeconomic spectrum in Seattle (Schaie, 1989). At each period of measurement, 25 male and 25 female subjects per year of birth were invited to participate in the study. The recruitment response ranged from 20% to 40% across all age groups solicited. Data were collected in six waves (1956, 1963, 1970, 1977, 1984, and 1991). With each new wave tested, an additional 7-year age interval was added to match the age range of the original samples up to age 81 (Schaie, 1996). None of the participants was suffering from any diagnosed dementia or severe disorders that prevented them from completing the assessment at the time of testing.

There were 601 decedents ($n = 342$ males; $n = 259$ females) who had been tested during one of the six waves and for whom death dates were known by December 1995. Dates of death were obtained from the subjects' HMO records or by checking Social Security Administration records that list the exact date of death. A control group of survivors ($N = 609$; $n = 296$ males; $n = 313$ females) was selected that was within 2 years of age and within 1 year of education of the decedents and, where possible, of similar gender. Survivorship included members of the control group who remained in the data base at the time of recruitment through the most recent cycle. Table 1 summarizes the demographic information for both decedents and survivors.

Measures

A brief discussion of all measures is included below. See Schaie (1996) for greater details regarding these measures.

Cognitive abilities.—The 1948 PMA 11-17 version of Thurstone's Primary Mental Abilities test includes the following subtests: Verbal Meaning, Spatial Orientation, Inductive Reasoning, Number, and Word Fluency (Thurstone & Thurstone, 1949).

Verbal Meaning is a test of recognition vocabulary. It is a multiple-choice test in which participants must identify one of four choices as a synonym of the presented word.

Spatial Orientation refers to the ability to think about objects in two-dimensional space and to mentally rotate them. Subjects select from six options and are instructed to circle all items that are a direct rotation (i.e., not mirror images) of the stimulus figure.

Inductive Reasoning involves logical problem solving and planning. This test measures the ability to identify patterns in a letter series. Subjects choose from among six items the one that logically follows in the stimulus sequence.

Number tests capacity to add numbers. Solutions to addition problems are given, and subjects decide whether the problem was solved correctly or not. Number ability is scored as the number of correct responses minus the number of wrong ones.

Word Fluency measures the ability to retrieve words from long-term storage, based on a lexical rule. Subjects are asked to list as many words that begin with the letter "S" as they can in 5 minutes. Word Fluency is scored as the number of valid words listed.

Verbal memory.—Verbal memory is assessed with the Immediate and Delayed Recall tasks. Verbal Memory was included in the test battery beginning in 1984, and only 257 individuals in this sample completed these two tasks. In the Immediate Recall task, participants study a list of 20 words for 3.5 minutes. They are then given an equal period of time to recall the words in any order. In the Delayed Recall task, the same list of words used for Immediate Recall is to be recalled by the participant after an hour of intervening activities (other psychometric tests; Zelinski, Gilewski, & Schaie, 1993).

Psychomotor speed.—Psychomotor speed indicates the individual's rate of emission of familiar cognitive responses. This factor score is obtained from the Test of Behavioral Rigidity (Schaie, 1996; Schaie & Parham, 1975) in which subjects are asked to copy a paragraph or to give synonyms or antonyms for simple words.

Perceptual speed.—Perceptual speed refers to the ability to quickly and accurately find objects and make comparisons, involving visual perception. Perceptual speed was assessed by three measures, all from the Educational Testing Service factor reference kit (Ekstrom, French, Harman, & Derman, 1976). The Finding A's Task and Identical Picture measures were reduced to 1.5 minutes because highly reliable findings (retest correlations of .860 and .814, respectively) with the shorter versions were obtained (Schaie & Willis, 1993). Schaie and colleagues have used the shortened measures since 1975 and have published norms for these measures using the shortened versions.

Finding A's Task requires the cancellation of the letter *a* in a column of words. This variable had been collected in the Seattle Longitudinal Study (SLS) since 1975, and 393 individuals

Table 1. Summary Demographics for Samples

Sample/Variable	*n*	Mean	*SD*	Range
Decedents	601			
Age		73.73	9.57	34–93
Education		12.83	3.43	1–20
Time in study (months)		79.97	56.55	1–264
Survivors	609			
Age		71.91	9.27	34–95
Education		12.97	3.13	4–20
Time in study (months)		179.58	90.48	1–480
Male decedents	342			
Age		73.58	9.40	38–93
Education		12.83	3.51	4–20
Time in study		78.26	58.08	1–324
Male survivors	296			
Age		70.57	9.76	39–95
Education		13.03	3.49	4–20
Time in study		175.5	89.80	60–396
Female decedents	259			
Age		73.93	9.79	34–93
Education		12.83	3.35	1–20
Time in study		86.11	62.50	1–432
Female survivors	313			
Age		73.28	8.38	34–91
Education		12.89	2.76	5–20
Time in study		185.75	89.25	60–480

completed this task. In each column of 40 words, the study participant must identify the five words containing the letter *a*. There are 50 columns of words.

Identical Pictures involves identifying which of five numbered shapes or pictures in a row is identical to the model at the left of the row; there are 50 items. This variable has been included in the study since 1975, and 451 individuals completed this measure.

Number Comparison requires comparing two sets of numbers and marking pairs that are not identical. There are 40 items, with a time limit of 1.5 minutes. Number Comparison has been included in the study since 1984, and 261 individuals completed this task.

Demographic information.—Various demographic and socioeconomic data have been collected since the inception of the SLS project (Schaie, 1996). This information included subjects' age, gender, and education.

Analyses

The SAS PHREG procedure was used to calculate Cox's semiparametric proportional hazard models to assess the effects of level of cognitive performance and cognitive decline on the probability of mortality. Survival analysis allows one to index the event in terms of when (whether calendar age or functional age) mortality has occurred. In other words, the unit of analysis in this study is the number of months lived. Odds ratios (OR) are obtained from survival analysis, and they are used to estimate the effects of cognitive performance on mortality. An OR represents the probability of mortality, given the level and decline of cognitive performance.

In the SLS data, left censoring is a problem; we do not know if a significant decline occurred prior to entry into the study. Right censoring is also problematic because the study was discontinued December 31, 1995, before all participants died. Maximum likelihood estimation was used, as it is best suited to deal with the problem of censored data (Blossfeld, Hamerle, & Mayer, 1989). Survival analysis can utilize time-varying explanatory variables and allow for the calculation of survival rates of risk factors for mortality. Thus, Cox proportional hazard models deal with the problem of explanatory variables that may themselves change over time and provide an estimated probability of survival (Schaie, 1989). Ordinary regression methods cannot deal with this issue.

Hierarchical models were estimated to successively introduce variables that can potentially confound the association between cognitive performance and mortality. Groups of independent variables were introduced block-by-block in a stepwise fashion as follows: (a) with cognitive performance at last measurement categorized as quartiles as the only variable in the model; (b) with the addition of sociodemographic factors (age, gender, education); and (c) psychomotor speed. Psychomotor Speed was treated as a covariate for all other cognitive measures. However, Psychomotor Speed was included in the model as an independent predictor of mortality. Dummy codes were used to represent each quartile of cognitive performance, and the referent point for each individual cognitive ability was performance in the top 25th percentile (see Appendix for cutoffs used). The use of dummy codes followed the conventional practice in previous studies using self-rated health (Bernard et al., 1997; Idler & Kasl, 1991; Kaplan & Camacho, 1983). Age was categorized by quartiles, and the youngest quartile was used as the referent age category. Education was categorized by 12 to 15 years, less than 11 years of education, and 16 years of education or more. The latter category was used as the referent category for education.

Because we were operating in a Thurstonian framework, we were interested in ability-specific change. Schaie and colleagues (1991) presented evidence that ability factors do not collapse upon each other and thus need to be separately investigated. In addition, separate models for each cognitive ability were analyzed to avoid problems of multicollinearity. Since there were random missing data for the PMA measures and not a substantial amount of missing data (0.5% to 7%), we used listwise deletion.

Hierarchical analyses were first conducted for level of cognitive performance for all participants. Then decline in cognitive level, as assessed by difference scores, was assessed in a similar hierarchical fashion as the level models. Finally, analyses were conducted in a similar hierarchical fashion except they were stratified by age; a median split was used to categorize older adults (≥ 74 years of age) and younger adults (≤ 73 years of age).

Results

Level of Cognitive Performance at Last Measurement

When the unadjusted association between cognition and mortality was examined, participants who were found to be in the lower 50th percentile on Spatial Ability, Delayed Recall, Immediate Recall, Psychomotor Speed, and Identical Pictures had a significantly increased probability of mortality compared to those individuals in the top 25th performance percentile on respective measures. Individuals who performed in the lower 25th percentile of Verbal Meaning and Numerical Ability had a significant relationship with mortality relative to their referent categories. The significant odds ratios ranged from 1.38 to 2.32 for the lowest percentile of performance (Table 2). After adjusting for sociodemographic factors, the odds ratios for many of the cognitive abilities decreased. This was particularly the case for Verbal Meaning, Numerical Ability, Spatial Ability, and Psychomotor Speed, where having low levels of cognitive performance on these respective measures was no longer a significant predictor of mortality once demographic factors were adjusted. Verbal memory (Immediate Recall, Delayed Recall) and a measure of perceptual speed (Identical Pictures) remained significantly related to a greater probability of mortality after adjusting for sociodemographic factors. However, once Psychomotor Speed was introduced into the model, only Identical Pictures remained significantly related to mortality.

Decline in Cognitive Performance

The influence of cognitive decline on mortality survival is shown in Table 3. There was a linear relationship in the degree of decline over the subsequent 7 years observed; increased decline was related to increased risk of mortality. Participants who had the greatest amount of 7-year decline in Verbal Meaning, Spatial Ability, Inductive Reasoning, and Psychomotor Speed had a 63%, 113%, 50%, and 97% greater likelihood, respectively, for mortality relative to their referent category after adjusting for sociodemographic factors and psychomotor speed.

Table 2. Odds Ratios and Confidence Intervals for Level of Performance

Independent Variables	Model I OR (95% CI)	Model II OR (95% CI)	Model III OR (95% CI)
Age (≤25th)		1.0	1.0
Age (26th–50th %)		NS	NS
Age (51st–75th %)		1.53 (1.19,1.98)	1.53 (1.18, 1.98)
Age (≥76th %)		2.17 (1.67, 2.82)	2.16 (1.66, 2.81)
Male		1.35 (1.14, 1.60)	1.35 (1.14, 1.60)
≥16 years of education		1.0	1.0
12–15 years of education		NS	NS
Less than high school (≤ 11 years)		1.26 (1.03, 1.53)	1.27 (1.04, 1.56)
Psychomotor Speed (continuous)			NS
Verbal Meaning (51st–75th %)	NS	NS	NS
Verbal Meaning (26th–50th %)	NS	NS	NS
Verbal Meaning (≤25th %)	1.67 (1.33, 2.08)	NS	NS
n = 1187			
Numerical Ability (51st–75th %)	NS	NS	NS
Numerical Ability (26th–50th %)	NS	NS	NS
Numerical Ability (≤25th %)	1.42 (1.14, 178)	NS	NS
n = 1204			
Spatial Ability (51st–75th %)	NS	NS	NS
Spatial Ability (26th–50th %)	1.32 (1.04, 1.69)	NS	NS
Spatial Ability (≤25th %)	1.38 (1.08, 1.75)	NS	NS
n = 1125			
Delayed Recall (51st–75th %)	NS	NS	NS
Delayed Recall (26th–50th %)	1.84 (1.05, 3.25)	1.88 (1.03, 3.42)	NS
Delayed Recall (≤25th %)	1.97 (1.09, 3.56)	NS	NS
n = 257			
Immediate Recall (51st–75th %)	NS	NS	NS
Immediate Recall (26th–50th %)	1.96 (1.10, 3.48)	1.98 (1.07, 3.67)	NS
Immediate Recall (≤25th %)	1.87 (1.07, 3.25)	NS	NS
n = 256			
Psychomotor Speed (51st–75th %)	NS	NS	NS
Psychomotor Speed (26th–50th %)	1.30 (1.02, 1.66)	NS	NS
Psychomotor Speed (≤25th %)	1.51 (1.18, 1.92)	NS	NS
n = 1089			
Identical Picture (51st–75th %)	NS	NS	NA
Identical Picture (26th–50th %)	1.75 (1.14, 2.67)	2.08 (1.31, 3.32)	2.07 (1.30, 3.31)
Identical Picture (≤25th %)	2.32 (1.56, 3.45)	2.80 (1.75, 4.80)	2.73 (1.64, 4.56)
n = 451			

Notes: OR = odds ratios; CI = confidence interval; NS = not significant; NA = not applicable.

Level and Decline in Cognitive Performance by Age Group

Interesting findings were obtained after analyses were conducted by stratifying median age. The oldest adults were 75 to 95 years of age or older, and the younger were 34 to 74 years of age. Level of performance on Identical Pictures remained a significant predictor of mortality for both age groups. However, the relationship appeared to be more profound among older adults, where those individuals in the lowest 50th percentile had a significant risk of mortality. Among the younger sample, only those in the bottom 25th had a significant risk of mortality compared to their referent categories. Examining the odds ratios, younger adults who had significant declines in Spatial Ability and/or Inductive Reasoning had a greater risk of mortality than older adults. Older adults who had significant declines in Verbal Meaning and Psychomotor Speed had greater risks of mortality than their younger counterparts (see Table 4).

Discussion

Level of cognitive function was found to be related to subsequent mortality, but the relationship of performance level and early mortality varied across abilities. Lower levels of crystallized abilities, visualization abilities, verbal memory, and perceptual speed as well as declines in Verbal Meaning, Spatial Ability, Inductive Reasoning, and Psychomotor Speed were significant predictors of mortality. Level of cognitive performance was related to mortality, but psychomotor speed mediated the relationship for many of these cognitive variables. Seven-year decline in cognitive performance was found to be a better predictor of subsequent survival than level of performance at last measurement, even after adjusting for demographic factors and psychomotor speed. Overall, the pattern of results in this study indicates that not all cognitive abilities are equally affected by terminal change or directly associated with

Table 3. Relative Risk Ratios and Confidence Intervals for Seven-Year Change Before Death

Independent Variables	Model I OR (95% CI)	Model II OR (95% CI)	Model III OR (95% CI)
Age (≤25th)		1.0	1.0
Age (26th–50th %)		NS	NS
Age (51st–75th %)		NS	NS
Age (≥ 76th %)		1.73 (1.19, 2.53)	1.67 (1.12, 2.48)
Male		1.37 (1.06, 1.71)	1.33 (1.01, 1.75)
≥ 16 years of education		1.0	1.0
12–15 years of education		NS	NS
Less than high school (≤ 11 years)		1.35 (1.01, 1.79)	1.38 (1.03, 1.85)
Psychomotor Speed (continuous)			NS
Verbal Meaning (51st–75th %)	NS	NS	NS
Verbal Meaning (26th–50th %)	NS	NS	NS
Verbal Meaning (≤25th %)	1.74 (1.19, 2.47)	1.68 (1.14, 2.47)	1.63 (1.10, 2.43)
$n = 556$			
Spatial Ability (51st–75th %)	NS	NS	NS
Spatial Ability (26th–50th %)	1.95 (1.32, 2.88)	1.96 (1.32, 2.89)	1.94 (1.31, 2.87)
Spatial Ability (≤25th %)	2.09 (1.40, 3.12)	2.13 (1.43, 3.19)	2.13 (1.43, 3.19)
$n = 557$			
Reason Ability (51st–75th %)	NS	NS	NS
Reason Ability (26th–50th %)	NS	NS	NS
Reason Ability (≤25th %)	1.45 (1.02, 2.07)	1.48 (1.03, 2.13)	1.50 (1.05, 2.16)
$n = 555$			
Psychomotor Speed (51st–75th %)	1.75 (1.15, 2.59)	1.71 (1.12, 2.59)	1.71 (1.12, 2.60)
Psychomotor Speed (26th–50th %)	2.06 (1.37, 3.10)	2.02 (1.34, 3.05)	2.05 (1.34, 3.13)
Psychomotor Speed (≤25th %)	2.10 (1.42, 3.12)	1.97 (1.32, 2.94)	1.97 (1.29, 3.00)
$n = 555$			

Notes: OR = odds ratios; CI = confidence interval; NS = not significant.

Table 4. Odds Ratios and Confidence Intervals for Level of Performance by Age Group

Independent Variables	Young (34–74 years) OR (95% CI)	Old (75–95 years) OR (95% CI)
Identical Picture (51st–75th %)	NS	NS
Identical Picture (26th–50th %)	NS	2.57 (1.16, 5.25)
Identical Picture (≤25th %)	2.80 (1.02, 7.66)	2.93 (1.40, 6.14)
Change Verbal Meaning (51st–75th %)	NS	NS
Change Verbal Meaning (26th–50th %)	NS	1.84 (1.07, 3.19)
Change Verbal Meaning (≤25th %)	NS	1.80 (1.06, 3.06)
Change Spatial Ability (51st–75th %)	NS	NS
Change Spatial Ability (26th–50th %)	2.48 (1.30, 4.72)	1.65 (1.01, 2.71)
Change Spatial Ability (≤25th %)	2.75 (1.42, 5.33)	1.72 (1.03, 2.87)
Change Reason Ability (51st–75th %)	NS	NS
Change Reason Ability (26th–50th %)	NS	NS
Change Reason Ability (≤25th %)	1.85 (1.04, 3.28)	NS
Change Psychomotor Speed (51st–75th %)	NS	NS
Change Psychomotor Speed (26th–50th %)	NS	2.64 (1.49, 4.70)
Change Psychomotor Speed (≤25th %)	NS	2.67 (1.27, 4.07)

Notes: Age, gender, education level adjusted; OR = odds ratios; CI = confidence interval; NS = not significant.

mortality after adjusting for age, gender, level of education, and psychomotor speed.

The relationship of Psychomotor Speed with mortality was one of the most consistent findings in this study, and the findings regarding Psychomotor Speed are similar to those reported by Birren (1968) and Kleemeier (1962); a significant decline in Psychomotor Speed is a risk factor for subsequent mortality. This study also indicated that some of the relationship between cognitive function and mortality as observed may be mediated by psychomotor speed, a measure of perceptual speed. There is growing evidence that perceptual speed is an important contributor to the decline in cognitive performance that occurs in many tasks (Earles & Salthouse, 1995; Salthouse, 1993b). Perceptual speed has been suggested to be a general mechanism underlying age-related differences on many cognitive tasks, including reasoning and spatial cognition (Mayr & Kliegel, 1993; Salthouse, 1985).

Despite the importance of perceptual speed being related to low levels and declines in cognitive performance, the relationship between health and perceptual speed is still mixed. While some researchers have found a negative relationship between self-reported health and cognitive performance (i.e., Field, Schaie, & Leino, 1988; Hultsch, Hammer, & Small, 1993; Perlmutter & Nyquist, 1990), others have found relatively little relationship (Salthouse, Kausler, & Saults, 1990). The use of self-reported measures of health could possibly explain the mixed findings of the relationship between health and perceptual speed. This relationship may differ when more objective measures of health, such as mortality, are used.

It is possible that perceptual speed simply reflects primary aging of the central nervous system (Birren, 1965; Birren et al., 1979; Swan et al., 1995). If slowing is a marker for central nervous system aging, then people with lower perceptual speed may be "older" physiologically than similarly aged individuals with higher perceptual speed; their mortality rates, in turn, would be correspondingly higher. Aging of the central nervous system might be expected to reduce adaptive capacity in a general way, thereby increasing susceptibility to death from a variety of causes.

Only a few studies have analyzed memory in relation to survival. Our finding, that verbal memory is related to survival, agrees with the results of Deeg et al. (1990), Small and Bächman (1997), and the Gothenburg Longitudinal Study (Johansson & Berg, 1989). However, much of the effects of verbal memory dissipated after Psychomotor Speed was included in the model. Because there were inadequate numbers of twice-measured individuals who had measures of verbal memory, the relationship between decline in verbal memory and mortality was not explored.

While level of Verbal Meaning, after adjusting for Psychomotor Speed, was not significantly related to mortality, a significant decrease in Verbal Meaning was related to increased mortality. The present findings are similar to past studies that have found verbal ability to be sensitive to mortality (Blum, Clark, & Jarvik, 1973; Reimanis & Green, 1971; Siegler, McCarty, & Logue, 1982; White & Cunningham, 1988). Verbal Meaning is known to be less sensitive to age than most other cognitive abilities, and vocabulary performance may be sensitive to the disease processes primarily responsible for death in the present deceased participants (Bosworth & Schaie, 1999; Cooney, Schaie, & Willis, 1988).

There was also evidence that decline in Spatial Ability, a measure of visualization ability, was related to mortality. Few studies have included Spatial Ability and examined its relationship with mortality. We reported earlier that survivors had significantly higher mean levels of Spatial Ability than decedents, but lacked significant mean declines as measured by difference scores (Bosworth & Schaie, 1999). It appears from this study that adults who have greater declines (bottom 50th percentile on Spatial Ability) are at a significant risk of mortality compared to those in the top 25th percentile.

Individuals who had the greatest amount of change (< 25th percentile) on Inductive Reasoning also had a significantly greater likelihood of mortality. Performance on Word Fluency, Number Comparison, and Finding A's Task was not found to be significantly related to mortality in this study. However, a linear relationship was observed similar to other cognitive functions. That is, individuals in the bottom percentile of performance had a greater likelihood of mortality than those in the top 25th percentile; however, these relationships were not significant.

The association between cognitive performance and subsequent mortality among younger adults (≤ 74 years) differed among older adults. Declines in age-related cognitive functions (i.e., Spatial and Reasoning Ability) were more of a risk factor among younger adults, whereas Verbal Meaning (crystallized ability) and two types of perceptual speed were greater risk factors among adults older than age 75 years. A possible explanation for this association between cognitive function and mortality across the two age groups is a consequence of the age-related trajectories of these variables. That is, adults tend to decline earlier on visualization and fluid abilities than crystallized abilities. Prior research has indicated that there are limited differences between survivors and decedents on mean level of cognitive performance; also, that the relationship between fluid and visualization abilities may represent an age-related association with mortality whereas crystallized abilities remain relatively stable, and a decline in this ability may signal impending death (Bosworth & Schaie, 1999; Cooney et al., 1988). Nevertheless, this relationship between age, cognition, and mortality may explain why past research has reported that certain age groups may appear to be more likely to exhibit terminal change than others.

The rate of decline observed in the study sample is likely to be an underestimation of the rate of decline experienced by the total initial sample, as a majority of the sample only had one measurement. Nevertheless, the relationship between 7-year cognitive decline and mortality was maintained after adjusting for the influence of psychomotor speed and sociodemographic variables. In previous research, we found that mean level of cognitive performance was more related to selective survival effects than to decline in cognitive performance (Bosworth & Schaie, 1999). However, by categorizing performance into quartiles, as opposed to examining decline in mean score, there is a subset of individuals who in this case declined significantly (lowest 25th percentile) and are at a significantly greater risk compared to those in the upper 25th percentile of performance, across various domains of cognitive function.

Christensen et al. (1994) suggested that, if one assumes that poor health mediates cognitive decline, decline would be expected to be greater for those aspects of cognition that are known to show greater age-associated declines (i.e., fluid ability, visualization ability, and psychomotor speed). This scenario appears to have been the case in the present study. The relationship between health and specific cognitive abilities (i.e., crystallized ability, fluid ability, memory, and perceptual speed) may partially explain the different developmental trajectories across the life span among these cognitive abilities.

Impending death may affect psychological functioning, or psychological functioning may affect subsequent mortality. The latter perspective could be the result of lower levels of cognitive functioning (e.g., failing to remember to take necessary medication) playing a causal role for subsequent mortality. In a similar fashion, individuals with more health problems deal less effectively with challenges of old age, and as a result may have an increased likelihood of dying. These possible scenarios need to be further explored.

This study's findings must be interpreted in light of a few caveats. First, the design of our study differed from many past studies, in that we used a sample of survivors who were selected to be of similar age and education as that of the decedents. Subsequently, the design of this study provided us an opportunity to both statistically and methodologically control for these important influences of cognition, similar to how the Gothenburg study examined individuals all born in the same year. The Gothenburg study included 280 subjects, all 70 years old when the study started (Berg, 1987). Although this method has the advantage of considering the effects of age and education, one must be cautioned when comparing the present findings with studies using more random samples.

Second, the study underrepresents the lower socioeconomic quartile of the U.S. population. Based upon previous findings, individuals with less than 12 years of education and lower levels of cognitive function had a greater risk of mortality than those with more than 12 years of education (Bosworth & Schaie, 1999). Subsequently, the risk of mortality may actually be more substantial with inclusion of those individuals in the lowest quartile.

This study is one of the largest to examine the relationship between cognition and mortality and, as such, findings could possibly be an artifact of the sample size. However, results discussed in this article were significant at the $p < .01$ level to adjust for the increased risk of capitalizing on chance afforded by the large sample size (Cox & Oakes, 1984). Similarly, because we treated age as categorical data, and the number of required interactions between cognitive function and age raised concerns over power and the number of tests conducted, we did not examine the interaction of age groups with cognition.

The results reported here do not consider the effects of diseases. Future studies should consider the role of disease to determine whether the relationship between cognition and mortality is independent or mediated by disease processes. In addition, after the memory and perceptual speed batteries were included in the SLS battery, fewer individuals were included in analyses, which explains the slightly larger confidence intervals for these measures.

To summarize, the consistency of the findings (after controlling for sociodemographic factors and Psychomotor Speed) strengthens the conclusion that the maintenance of cognitive functions is an independent risk factor for mortality, although it does not rule out the possibility that other uncharacterized or unrecognized conditions may be responsible for both decline in cognitive function and death. A relationship between cognition and health was observed in this study. This relationship tended to be specific, particularly affecting perceptual speed, and a stronger association among decline in cognitive performance versus level of cognitive performance was observed.

Acknowledgments

This study was conducted as part of the first author's doctoral dissertation under the direction of Dr. Schaie. Part of this study was presented at the Sixth Cognitive Aging Conference, Atlanta, GA. This research is supported by Grant R37 AG08055 from the National Institute on Aging to Dr. Schaie, and partial support for the preparation of the manuscript was from a predoctoral fellowship training grant (T32 MH18904-07) and a postdoctoral fellowship training grant (5 T32 MH19109-5) from the National Institute of Mental Health.

The authors acknowledge comments on earlier versions of this article by Rebecca A. Essinger, Toni P. Miles, Ilene C. Siegler, and Steven H. Zarit. In addition, the authors gratefully acknowledge the members and staff of the Group Health Cooperative of Puget Sound for their enthusiastic collaboration.

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Received November 7, 1997
Accepted February 25, 1999

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