Age and Distance to Death in the Seattle Longitudinal Study

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A series of hierarchical regression models was used to determine if time to death was a significant independent variable for level and seven-year change in intellectual performance for 1,214 community-dwelling adults. Distance to death explained a significant amount of the variance of intellectual performance at individuals' last measurement but not of the decline in performance after controlling for age, education, gender, and survivorship. The inclusion of time to death improved the proportion of unique variance explained by about 1% to 3% and between 4% and 10.4% of the total variance explained. Decedents had lower levels of verbal meaning, spatial ability, reasoning ability, and psychomotor speed at last measurements and greater amounts of seven-year decline on verbal meaning and psychomotor speed. The inclusion of distance to death may help improve the explanation of variability in performance associated with increased age.

While previous studies have used chronological age (e.g., Schaie 1983, 1996), education (e.g., Evans et al. 1993; Schaie 1990), and gender (e.g., Schaie 1983, 1996) to explain changes in intellectual

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function in later life, an additional factor may be distance to death. There has been evidence to suggest that intellectual function is negatively related to survivorship and that some portion of the age differences in intellectual performance may be accounted for by the distance to death (Berg 1996; Bosworth and Schaie 1999; Cooney, Schaie, and Willis 1988; Deeg, Kardaun, and Fozard 1996; Liu et al. 1990; Siegler 1975; Swan, Carmelli, and LaRue 1995; White and Cunningham 1988). Decreases in intellectual performance may be related to distance to death instead of a particular age, and the maintenance of function should be associated with survival (Siegler 1975). The present study was interested in examining how distance to death is related to both level and decrements in intellectual function after accounting for traditional factors associated with intellectual performance.

Riegel and colleagues raised the possibility that distance to death may account for the apparent decline in intellectual functioning with age as observed in cross-sectional studies. Older individuals may be closer to death, and the proportion of persons close to death increases with age, which may be primarily responsible for the observed age difference in intellectual abilities (Riegel and Riegel 1972; Riegel, Riegel, and Meyer 1967). White and Cunningham (1988) suggested that distance to death introduces an influence in addition to normal or primary aging; distance to death could be related to intellectual functioning as a secondary influence on performance. Berg (1996) reviewed a number of studies examining the relationship between intellectual function and mortality and concluded that there is conflicting evidence as to whether the association between mortality and intellectual function is global or involves only selected abilities.

Since there is variability among individuals of the same chronological age, distance to death may be an index of this variance. For example, two 70-year-olds may perform at different levels of intellectual performance and it is possible that part of the variance could be accounted for by the fact that one adult has a shorter distance to death than the other. Thus, the present study examined whether distance to

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death can better improve the prediction of intellectual performance than simply using chronological age and demographic factors.

The Seattle Longitudinal Study (SLS) provides an opportunity to explore the relationship between intellectual function and survivorship and distance to death for various mental abilities in a large community-dwelling sample. Two methods were used to examine whether variation in decline and level of intellectual performance may be attributed to the distance to death. First, differences between survivors and decedents in mean level of intellectual performance at individuals' last measurement were examined. Last measurement refers to the last time an individual was measured before death or the conclusion of the study. In addition, differences in amount of decline between individuals' last two measurements over seven years were studied. It is at this point that individuals would likely be experiencing significant decrements in intellectual performance (Bosworth and Schaie 1999). One-way analyses of variance (ANOVAs) were used to test mean differences between survivors and decedents at first and last measurement and the change between the last two measurements.

The second method used was hierarchical regression modeling to determine whether distance to death is independently related to both level and change in intellectual performance. A set of two models was conducted. Age, educational attainment, and gender, followed by survivorship, were first placed in the model. Survivorship was included in the model because it was only moderately correlated ($r = .54$) with distance to death. The relationship between distance to death was then examined. The second model examined seven-year change in distance to death between individuals' last two measurements ($n = 614$). Distance to death was operationalized as the number of months between last measurement and death for decedents and number of months between last measurement and December 31, 1995, for survivors. After considering variables known to be related to declines in intellectual function, it was hypothesized that distance to death would remain a significant predictor of intellectual performance and explain a unique proportion of intellectual function. Based on a prior study, it was hypothesized that decedents would have significantly lower levels and greater change on psychomotor speed, as measured by the Test of Behavioral Rigidity scale, and crystallized abilities, particularly verbal meaning, as compared to survivors (Bosworth and Schaie 1999).

Methods

SUBJECTS

The SLS is a cohort-sequential study that has collected data on more than 5,000 participants between the ages of 22 and 95. Subjects 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 seven-year age interval was added to match the age range of the original samples up to age 81 years (Schaie 1996). All participants were able to complete the measurement battery.

When exploring the relationship between cognition and mortality, it is necessary also to consider the possible presence of dementia. The SLS does not contain any formal neuropsychological screening measures for dementia. However, the test battery extends over two and a half hours using paper-and-pencil tests. Given the mental demands of the test battery, individuals who might be suffering from severe to moderate dementia are unable to participate. Empirical evidence supports this conclusion. For the approximately 4,000 subjects tested in the SLS, about 500 have had at least seven or more years of medical data abstracted, and only 6 of these 500 subjects had a diagnosis of dementia subsequent to the last assessment. In addition, 107 of the 605 subjects who have died had their medical data abstracted up to or within two years of their death and only two were believed to have symptoms of some type of dementia.

Decedents

There were 605 decedents (n = 343 males, n = 262 females) who had been tested during one of the six waves and for whom dates of death were known by December 31, 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. The average age of this sample at their last measurement before death was M = 73.73 (SD = 9.56, range = 34-93 years), and they had approximately 12.83 years of education (SD = 3.44, range = 1-20). Table 1 contains information on age, level of education, and months between last measure and death, which represents distance to death for the decedents. Seven individuals were tested six times (spanning 35 years), 22 had five test measurements (28 years), 57 had four test measurements (21 years), 75 had three test measurements (14 years), 132 had two points of measurement (7 years), and 312 had only one measurement before dropping out of the study. Thus, 293 subjects had at least two points of measurement (see Table 2).

Survivors

A control group consisting of 609 survivors (n = 296 males, n = 313 females) was selected who were within two years of age and within one year of education of the decedents. All survivors were still present in the SLS database at the time of recruitment for the most recent cycle. The average age of this sample at their last measurement was M = 71.91 (SD = 9.27, range = 34-95 years), and they had approximately 12.97 years of education (SD = 3.13, range = 1-20). There were 321 participants who were tested two or more times over 7 to 35 years (see Table 3). Survivors did not differ from decedents in terms of family income, race, age, education, or gender distribution at last measurement.

This study has sufficient subjects to detect small effects. Thus, results discussed in this article focus on only a significance level of $p < .05$ to avoid capitalizing on chance afforded by the large sample size (Cox and Oakes 1984).

TABLE 1
Summary Demographics for Samples

Sample	*Variable*	N	M	SD	*Range Percentage*
Decedents	Age	605	73.73	9.57	34-93
	Education		12.83	3.43	1-20
	Time (months)		79.97	56.55	1-264
Survivors	Age	609	71.91	9.27	34-95
	Education		12.97	3.13	4-20
	Time		179.58	90.48	1-480

NOTE: Time refers to number of months between last measurement and conclusion of the study. Conclusion of study represents date of death for decedents or December 31, 1995, for the survivors.

TABLE 2
Number of Subjects per Number of Measurements for Decedents

Frequent Measurements	*Total Male*	*Total Female*
At least 1	343	262
2 or more	159	134

MATERIALS

Various demographic and socioeconomic data have been collected since the inception of the SLS project (Schaie 1996). This information included subject's age, family income, gender, and education. Intellectual abilities were measured with the 1948 PMA 11-17 version of the Thurstone's Primary Mental Abilities Test, which includes the following subtests: Verbal Meaning, Word Fluency, Numerical Ability, Spatial Orientation, and Inductive Reasoning (Thurstone and Thurstone 1949).

Verbal Meaning is a test of recognition of vocabulary. It is a multiple-choice test in which subjects must identify one of four choices as a synonym of the presented word. 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 five minutes. Word Fluency is scored as the number of

TABLE 3
Number of Subjects per Number of Measurements for Survivors

Frequent Measurements	*Total Male*	*Total Female*
At least 1	296	313
2 or more	159	162

valid words listed. Numerical Ability 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. 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 the 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. Psychomotor Speed was also assessed, and it indicates the individual's rate of responding to familiar cognitive responses. This factor score is obtained from the Test of Behavioral Rigidity (Schaie 1996; Schaie and Parham 1975), in which subjects are asked to copy a paragraph or to give synonyms or antonyms for simple words.

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). Crystallized intelligence remains relatively stable, whereas fluid intelligence, visualization ability, and psychomotor speed decline steadily with increased age (Horn 1982; Schaie 1983, 1996).

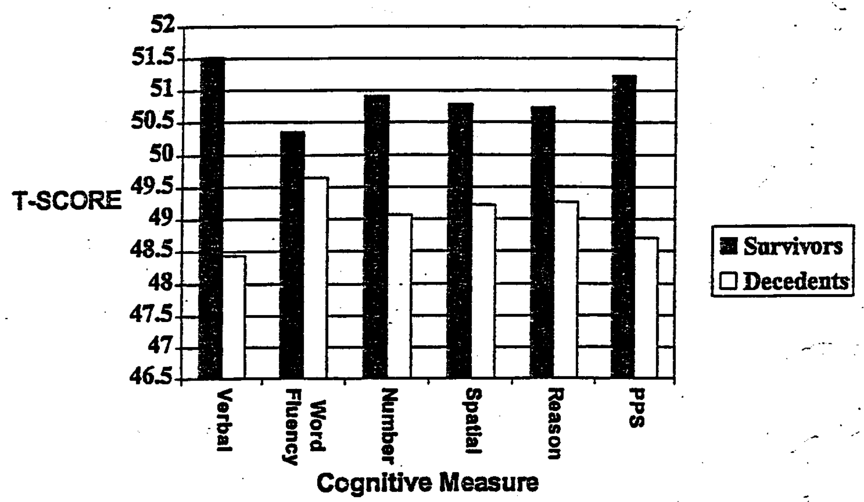

Figure 1: Cognitive Performance at Last Measurement by Survivorship
NOTE: PPS = Psychomotor Speed; Standardized to *T*-scores, mean = 50, standard deviation = 10.

Results

MEAN DIFFERENCES IN PERFORMANCE

As shown in Figure 1, across all intellectual measures, decedents had lower levels of performance than survivors at last measurement adjusting for age, education, and gender. Differences in levels were calculated using one-way ANOVAs. Decedents had significantly lower levels of performance than survivors at last measurement for verbal meaning, $F(1, 1186)$, 28.85, $p < .001$; numerical ability, $F(1, 1206)$, 10.43, $p < .001$; spatial ability, $F(1, 1127)$, 6.97, $p < .008$; reasoning ability, $F(1, 1193)$, 6.50, $p < .01$; and psychomotor speed, $F(1, 1186)$, 17.70, $p < .001$.

Both decedents and survivors who had at least two measurements declined between their last two measurements, as would be expected. However, as indicated by Figure 2, decedents declined significantly more than survivors on verbal meaning, $F(1, 547) = 15.47, p < .001$;

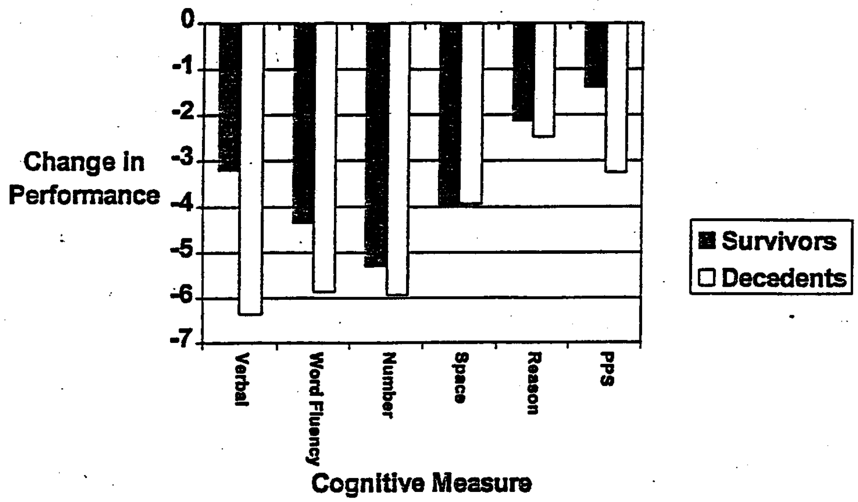

Figure 2: Seven-Year Change in Cognitive Performance by Survivorship
NOTE: PPS = Psychomotor Speed.

numerical ability, $F(1, 553) = 5.69, p < .02$; and psychomotor speed, $F(1, 547) = 22.56, p < .001$.

HIERARCHICAL REGRESSION

Hierarchical regression models were estimated to determine if distance to death was a significant independent variable for level of intellectual performance and change in intellectual performance after controlling for the effects of age, gender, and education. Age, education, and gender were first entered into the models, followed by survivorship and then distance to death in months. Age, gender, and education accounted for the largest portion of the variance in the six levels of performance models (see Table 4). With the exception of numerical ability, distance to death explained a unique portion of the model variance. However, the amount of unique variance explained by distance to death was low; it ranged from 1% to 3% among the six models, which was 4% to 10.4% the amount of the total variance explained. The total variance explained ranged from 13% to 32% among the six models.

TABLE 4
Hierarchical Regression for Last Measurement
(standardized beta weights)

Model	*Verbal Meaning*	*Word Fluency*	*Numerical Ability*	*Spatial Ability*	*Inductive Reasoning*	*Psychomotor Speed*
1. Age	–.38***	–.26***	–.24***	–.38***	–.39***	–.31***
Education	.34***	.26***	.22***	.13***	.29***	.37***
Gender[a]	—	.15***	–.06*	–.19***	.05*	.20***
2. Survivorship[b]	–.10***	—	–.07*	–.07*	—	–.07**
3. Distance to death (months)	–.16***	–.09*	—	–.11**	–.23***	–.18***
4. ΔR^{2c} (%)	2	1	—	1	3	2
5. Total R^2 (%)	32	16	13	24	29	31

a. 0 = female; 1 = male.
b. 0 = survivor; 1 = decedent.
c. Unique variance distance to death explains.
*$p < .05$. **$p < .01$. ***$p < .001$.

Change between individuals' last two measurements was examined next. A difference score was used to calculate change. Here, distance to death explained little variance in the models that examined change between last two measurements. Only age was significantly related to change, and age only explained between 4% and 6% of the total variance (see Table 5).

Discussion

There was evidence that intellectual performance is negatively related to subsequent mortality. Decedents had lower levels of intellectual performance at last measurements as well as greater rates of change across last two measurements than did survivors. In addition, some portion of intellectual performance was accounted for by individuals' distance to death. There was evidence in this study that distance to death explained increases in variance with age for intellectual measures.

Our findings, that across all intellectual measures decedents had lower levels of performance than survivors at last measurement, was similar to Berg (1987). Unlike the level of measurement analyses, distance to death was not highly related to change in intellectual

TABLE 5
Hierarchical Regression for Change Between Last Two Measurements (standardized beta weights)

Model	*Verbal Meaning*	*Word Fluency*	*Numerical Ability*	*Spatial Ability*	*Inductive Reasoning*	*Psychomotor Speed*
1. Age	–.23***	–.24***	–.21***	–.21***	–.21***	–.19***
Education					.15**	
Gender[a]						
2. Survivorship[b]						
3. Distance to death (months)						
4. ΔR^{2c}						
5. Total R^2 (%)	6	6	5	5	7	4

a. 0 = female; 1 = male.
b. 0 = survivor; 1 = decedent.
c. Unique variance distance to death explains.
*$p < .05$. **$p < .01$. ***$p < .001$.

performance. Similar to past studies (Cooney et al. 1988), individuals who are lost from a panel study function at a lower level than those who remain in the sample. This finding is similar to one reported by Deeg, Hofman, and Van Zonneveld (1990). It seems plausible that what really matters for survival is not one's baseline performance, but one's level of performance at the conclusion of the study (Deeg et al. 1990). However, with only one measurement available for the majority of those who died (52%), there is no way of determining how their intellectual function changed and how this change was related to their longevity. The rate of change observed in the study sample is likely to be an underestimation of the rate of change experienced by the total initial sample. Those individuals with multiple measures did not differ in terms of age, education, income, or gender distribution. However, it is likely that those individuals who remained in the study for seven or more years possessed certain characteristics other than these demographic factors that differentiated themselves from those who had only one measure.

Verbal meaning and psychomotor speed were consistently related to survivorship and distance to death in this study. Past studies have found verbal ability to be uniquely sensitive to mortality (Blum, Clark, and Jarvik 1973; Bosworth and Schaie 1999; Reimanis and Green 1971; Siegler, McCarty, and Logue 1982; White and

Cunningham 1988). Verbal meaning is known to be less sensitive to age than most other intellectual abilities, and vocabulary performance may be sensitive to the disease processes primarily responsible for death in the present deceased participants (Bosworth 1996; Cooney et al. 1988). Similarly, psychomotor speed, a measure of perceptual speed, has also been previously found to be associated with mortality (Birren 1968; Kleemeier 1962). There is growing evidence that perceptual speed is an important contributor to the decline in intellectual performance that occurs in many tasks (Bosworth, Schaie, and Willis forthcoming; Earles and Salthouse 1995; Salthouse 1993).

Distance to death may offer an additional explanation for the observed discrepancy between cross-sectional findings that tend to show a steady decrement of function with age and longitudinal findings that often maintain stable levels of function among healthy long-term survivors. Riegel and Riegel (1972) suggest that older individuals are closer to death and the proportion of persons close to death increases with age, which may contribute to age differences in intellectual abilities and differences between cross-sectional and longitudinal findings. The implication of this conclusion is that consecutive age samples drawn from the population will not be homogeneous, which is consistent with our earlier findings (Bosworth 1996; Bosworth and Schaie 1999).

The present findings caution against treating samples of elderly persons as being homogeneous. Normative samples of elderly persons may contain an appreciable number of individuals experiencing terminal change. Averaging the performance of both healthy persons and individuals who are relatively close to death may lead to the erroneous interpretation that everyone (including healthy older adults) experiences a decline in all intellectual abilities. The inclusion of individuals experiencing effects due to their closeness to death may inflate the observed interindividual differences, and the inclusion of premorbid individuals may decrease reported levels of intellectual performance and increase estimated rates of intellectual decline for older samples.

Distance to death explained a unique portion of the variance for five of the six measures of intellectual performance. Birren and Cunningham (1985) developed the Cascade Model, which posits a particular pattern of aging and seeks to explain several aspects of intellectual functions and includes the concept of distance to death. Their model contains three facets of aging: primary aging (normal), secondary aging (disease-related), and what they refer to as tertiary aging (which could represent distance to death). Three classes of intellectual functions are represented in this model: crystallized abilities, fluid abilities, and perceptual speed. The model postulates a particular pattern of causal influences. The hypothesized causal pattern is as follows: primary aging is believed to influence perceptual speed but not other aspects of intellectual functioning. Many studies in the research literature suggest normal aging results in a slowing of speed with which information is processed (Birren and Cunningham 1985; Salthouse 1985). Secondary aging is hypothesized to influence both perceptual speed and fluid abilities. There is evidence to suggest that low health status may be responsible for increased losses with age, even when chronological age is held constant. Finally, distance to death influences tertiary aging; this concept is viewed as being pervasive, and therefore causal links are postulated with all three aspects of intellectual function (Birren and Cunningham 1985).

It is important to note that the hierarchical regression model used to examine the increase in variance explained after age, education, gender, and survivorship were entered in the equation is a conservative test for distance to death because it assigns all the joint variance explained by the first four variables and distance to death to those variables first placed in the model. However, since we were interested in examining the unique effect of distance to death, this method seems appropriate for removing the influence of aging effects.

The design of the SLS does not allow for a full test of the distance from death hypothesis because possible health changes within the final seven-year interval were not measured nor is there information available on cause of death. While not screening for cause of death guarantees that there will be some extra error variance in the data since individuals may have died from acute illnesses or events, the relationship between intellectual function and distance to death and survivorship may be underestimated in this study and support the consideration of these factors when examining intellectual functions in older adults. Nevertheless, these data provide empirical support that distance to death explains a unique portion of the variance for level of intellectual performance in a large-community-dwelling sample.

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