Survival Effects in Cognitive Function, Cognitive Style, and Sociodemographic Variables in the Seattle Longitudinal Study

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Survival effects in cognitive performance were examined in the Seattle Longitudinal Study (SLS) for a sample of 605 individuals who subsequently died (decedents) ($n = 343$ males; $n = 262$ females; $M = 73.73$ years of age) and a control group of 613 survivors ($n = 299$ males; $n = 314$ females; $M = 71.91$ years of age). A sample of survivors of similar age and have a similar level of education as the decedents was selected. Differences in cognitive functioning and cognitive style in level and change over time between decedents and survivors were studied. Decedents had lower levels of crystallized abilities (Verbal Meaning and Numerical Ability), visualization abilities (Spatial Orientation), verbal memory (Delayed Word Recall), perceptual speed (Identical Pictures),

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and Psychomotor Speed at last measurement. Decedents also had greater declines on Psychomotor Speed and Verbal Meaning at 7 and 14 years before the conclusion of the study. Survival effects were found to be ability-specific, appeared primarily in older adults, were more evident for males, and were observed up to 14 years before last measurement for specific abilities. Age-related changes in fluid ability appeared to be normative, whereas changes in crystallized abilities and perceptual speed may signify impending mortality.

Longitudinal studies of intellectual ability have shown stability prior to 60 years of age but, by age 70 and older, reliable decrements have been found (Schaie, 1996). Fluid abilities and visualization abilities have been observed to decline earlier, whereas crystallized abilities appear to show a steeper decrement once the late 60s are reached (Kaufman & Horn, 1996; Schaie, 1983, 1996; Steuer & Jarvik, 1981; Wang & Kaufman, 1993).

There has been evidence to suggest that cognitive function is negatively related to subsequent mortality and that some portion of the age differences in cognitive performance may be accounted for by the presence of terminal change (Cooney, Schaie, & Willis, 1988; Liu, LaCroix, White, Kittner, & Wolf, 1990; Siegler, 1975; Swan, Carmelli, & LaRue, 1995; White & Cunningham, 1988). Decreases in cognitive performance may occur in proximity to death rather than at a particular age and the maintenance of function should be associated with survival (Siegler, 1975). Therefore, survival effects are important in studies of level and change in intellectual function.

Although survival effects may help explain differences in level and rates of change in cognitive performance, a number of studies of this phenomenon have disagreed as to whether survival effects are pervasive across all cognitive abilities (i.e., Berg, 1987) or whether they are restricted to specific abilities (e.g., Siegler, McCarty, & Logue, 1982; White & Cunningham, 1988). The conflicting findings in the literature can be attributed to the fact that some researchers (Berg & Jeppson, 1991; Bruce, Hoff, Jacobs, & Leaf, 1995; Deeg, Hofman, & Van Zonneveld, 1990; Johansson & Berg, 1989; Swan et al., 1995) focused on single measures of cognitive ability or that they studied relatively few abilities in relation to time to death (e.g., White & Cunningham, 1988).

Many of these studies have examined the relation of level of performance to mortality, but they have not assessed the magnitude of change in performance over a period of time preceding death (Swan et al., 1995; Perls, Morris, Ooi, & Lipsitz, 1993; White & Cunningham 1988). Although there is some evidence to suggest that low levels of cognitive function are related to increased risks of mortality (Aronson et al., 1991; Bruce et al., 1995; Liu et al., 1990), reports of longitudinal studies relating change in cognitive function to survival in samples of general population are contradictory. Some investigators have suggested that there is a "critical" decline in cognitive function that separates survivors from decedents (Berg, 1987, 1996; Deeg et al., 1990; Jarvik & Blum, 1971). Other investigators have not found any relation between change in cognitive function and survival (Botwinick, West, & Storandt, 1978; Bruce et al., 1995; Steuer, LaRue, Blum, & Jarvik, 1981).

Many earlier studies have not included women in their sample (i.e., Kleemeier, 1962; Swan et al., 1995). The exclusion of women in studies of survival effects is problematic because of the systematic gender differences in cognitive performance (Schaie, 1996) and because of greater longevity for women (USHHS, 1993).

With the exception of more recent epidemiological studies, many previous studies have been based on relatively small samples (e.g., Kleemeier, 1962; Lieberman, 1965). Moreover, potential covariates of the cognitive decline-mortality relationship, such as age and education, have not been well controlled in prior studies. The literature on age changes in cognitive abilities is extensive and findings indicate not only that cognitive function decline with age but also that the rates of decline differ across intellectual abilities (Schaie, 1996). Educational history has been one of the most consistent predictors of cognitive change, with higher levels of education being associated with greater maintenance of cognitive performance (Schaie, 1996).

Cognitive style, specifically, attitudinal rigidity has also been related to survival effects. For instance, Cooney and colleagues (1988) reported that individuals who dropped out of the study panel because of illness or death tended to be more rigid than other groups prior to attrition. Cooney et al. attribute their findings to the fact that attitudinal rigidity contributes to illness and deterioration which often result in nonparticipation. Individuals who are inflexible might be relatively unwilling to change their lifestyles and behavior in order to avoid the occurrence or to manage the effects of certain diseases.

The first goal of this study was to elucidate the differences in levels of cognitive functioning and cognitive style of decreased and surviving individuals. Past research has indicated that, prior to death, individuals perform worse on cognitive abilities in comparison to study participants who are known to survive. It was therefore hypothesized that decedents would show lower levels of cognitive abilities and cognitive style than survivors at individuals' last measurement. Additionally, this study was interested in examining how early these survival effects were observable.

The second goal was to examine differences in rates of decline between decedents and survivors. Relatively little is known about differences in rates of decline in cognitive function and cognitive style between survivors and decedents. It was hypothesized that decedents' rates of decline would be significantly greater than those of survivors across both 7 and 14 years.

METHODS

The Seattle Longitudinal Study (SLS) has collected data on more than 5,000 participants between the ages of 22 and 95. Participants were selected randomly within gender and age/cohort groups from the membership of 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. By comparison with area census figures, the sample under-represents the lowest socioeconomic segment of the population, but is a reasonable representative of at least the upper 75% SES (Socioeconomic Status) range of the population of Seattle (Schaie, 1996). At each measurement occasion, 25 male and 25 female participants per 7-year age/cohort 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 81 years of age (see Schaie, 1996, for greater details). No participants suffered from any diagnosed dementia or other severe disorders at any measurement that would have prevented completion of the assessment protocol.

There were 605 decedents ($n = 343$ males; $n = 262$ females) included in the present analyses who had been tested during one of the six waves and had known death dates prior to December, 1995. Dates of death were obtained from the participants' HMO

records or by checking Social Security Administration records, which list the exact date of death. A control group of 613 survivors ($N = 613$; $n = 299$ males; $n = 314$ females), who were within 2 years of age and within 1 year of education level of the decedents, was selected. Table 1 summarizes the demographic information for both decedents and survivors.

Cognitive Abilities

Thurstone Primary Mental Abilities (PMA)

The 1948 PMA 11–17 version of the Thurstone's Primary Mental Abilities test was used in this study (Thurstone, 1948). This test includes the following subtests in the order they are given: Verbal Meaning, Inductive Reasoning, Spatial Orientation, Number, and Word Fluency. Verbal Meaning, Word Fluency, and Numerical Ability of the Primary Mental Abilities represent crystallized abilities, whereas Spatial Orientation is a measure of

TABLE 1 Summary Demographics for Samples

Sample	Variable	*N*	*M*	*SD*	Range
Decedents	Age	605	73.73	9.57	34–93
	Education		12.83	3.43	1–20
	Time in study		79.97	56.55	1–264
Survivors	Age	613	71.91	9.27	34–95
	Education		12.97	3.13	4–20
	Time in study		179.58	90.48	1–480
Male decedents	Age	343	73.58	9.40	38–93
	Education		12.83	3.51	4–20
	Time in study		78.26	58.08	1–324
Male survivors	Age	299	70.57	9.76	39–95
	Education		13.03	3.49	4–20
	Time in study		175.5	89.80	60–396
Female decedents	Age	262	73.93	9.79	34–93
	Education		12.83	3.35	1–20
	Time in study		86.11	62.50	1–432
Female survivors	Age	314	73.28	8.38	34–91
	Education		12.89	2.76	5–20
	Time in study		185.75	89.25	60–480

Note. Time in study for decedents equals months from last measurement to death. Time in study for survivors equals months from last measurement to the conclusion of the study.

visualization ability and Inductive Reasoning is a measure of fluid ability. Crystallized abilities involve the formation of skills and strategies that people acquired through experience. Visualization ability involves perceiving and thinking with visual patterns and spatial configurations. Fluid ability is characterized by skill in dealing with novel problems and being able to perceive and discriminate relations (Cattell, 1963; Schaie, 1996; Woodcock, 1990).

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.

Inductive Reasoning involves logical problem solving, foreseeing, and planning. This test measures the ability to identify patterns in a letter series.

Spatial Orientation refers to the ability to think about objects in two-dimensional space and to mentally rotate them.

Number involves addition skills. Solutions to addition problems are given, and participants decide whether the problem was solved correctly or not.

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

Verbal Memory was assessed by means of two-list learning tasks. In an Immediate Recall task, participants study a list of words. 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 recalled by the participant after an hour of intervening activities (Zelinski, Gilewski, & Schaie, 1993).

Perceptual Speed was assessed by three measures, all from the Educational Testing Service factor reference kit (Ekstrom, French, Harman, & Derman, 1976). All three measures are timed tasks.

Finding A's task requires the cancellation of the letter "a" in a column 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.

Number Comparison requires comparing two sets of numbers and marking pairs that are not identical.

The Test of Behavioral Rigidity (TBR) contains three dimensions: Motor-Cognitive Flexibility, Attitudinal Flexibility, and Psychomotor Speed (see Schaie, 1996, for greater details). Motor-Cognitive Flexibility measures the ability to shift from one task to another. Attitudinal Flexibility measures the ability to perceive and adjust to new and unfamiliar patterns and interpersonal situations. Psychomotor Speed indicates the individual's rate of emission of familiar cognitive responses.

Personal Data

Various demographic and personal information has been obtained since the inception of the SLS project (see Schaie, 1996, for greater detail). This information includes participants' age, family income, gender, and education.

RESULTS

Survival Effects for Cognitive Ability and Cognitive Style at Last Measurement

Differences between survivors and decedents at their last time of measurement were examined using a series of 2 (gender) × 2 (survival status) × 4 (age groups) analyses of covariances (ANCOVAs) for the cognitive abilities and cognitive styles while controlling for education. Education was treated as a covariate because of its correlation with the independent variables. Status represented survivors or decedents and age groups referred to middle-aged (<65 years; $n = 245$), young-old (65–75 years; $n = 370$), old-old (75–80 years; $n = 347$), and the oldest-old (81 + years; $n = 256$ years of age). Differences between means were examined with Studentized Tukey's post-hoc tests. Table 2 summarizes the results of the ANCOVA models for level of cognitive performance and cognitive style. Last time of measurement was examined because all participants were included in these analyses.

Survivors had significantly higher performance levels for crystallized abilities (i.e., Verbal Meaning and Numerical Ability), visualization abilities (i.e., Spatial Ability), perceptual speed (i.e., Identical Pictures), and Psychomotor Speed than decedents. In addition to the survivorship effects, significant interactions were found between survival and age groups. As indicated in Figures 1 through 3, old-old and oldest-old decedents had significantly lower levels of Verbal Meaning, Numerical Ability, and Psychomotor Speed than their surviving counterparts. However, there

TABLE 2 Summary of Significant Univariate F Ratios for Cognitive Abilities and Cognitive Style at Last Measurement Adjusted for Education

Main effects and interactions	Verbal meaning	Space	Reasoning	Number	Word fluency
Gender		58.20*** (1,1119)		4.12* (1,1198)	30.94*** (1,1198)
Survival	17.58** (1,1174)	3.75* (1,1119)		3.72* (1,1198)	
Age group	87.68*** (3,1174)	66.24*** (3,1119)	75.70*** (3,1185)	38.14*** (3,1198)	35.41*** (3,1198)
Gender × Survival				4.24* (3,1198)	
Gender × Age Group					
Survival × Age Group	5.56*** (3,1174)			3.12* (3,1198)	8.48*** (3,1198)

Main effects and interactions	Immediate recall	Delayed recall	Finding A's	Identical pictures	Number comparison
Gender	13.48*** (1,242)	17.63*** (1,243)	8.65** (1,367)	4.14*** (1,427)	6.37* (1,238)
Survival				24.62*** (1,427)	
Age group	5.07** (3,242)	5.45*** (3,243)	4.56** (3,367)	25.11*** (3,427)	4.77** (3,238)
Gender × Survival					
Gender × Age Group					
Survival × Age Group					

TABLE 2 *(Continued)*

Main effects and interactions	Motor-cognitive flexibility	Attitudinal flexibility	Psychomotor speed
Gender		5.54* (1,1099)	48.02*** (1,1077)
Survival			7.12** (1,1077)
Age group	27.18*** (3,1092)	26.41*** (3,1099)	46.81*** (3,1077)
Gender × Survival			5.38* (3,1077)
Gender × Age Group			
Survival × Age Group			4.23** (3,1077)

Note. Degrees of freedom in parentheses; *F* ratios above parentheses. *$p < .05$; ** $p < .01$; *** $p < .001$.

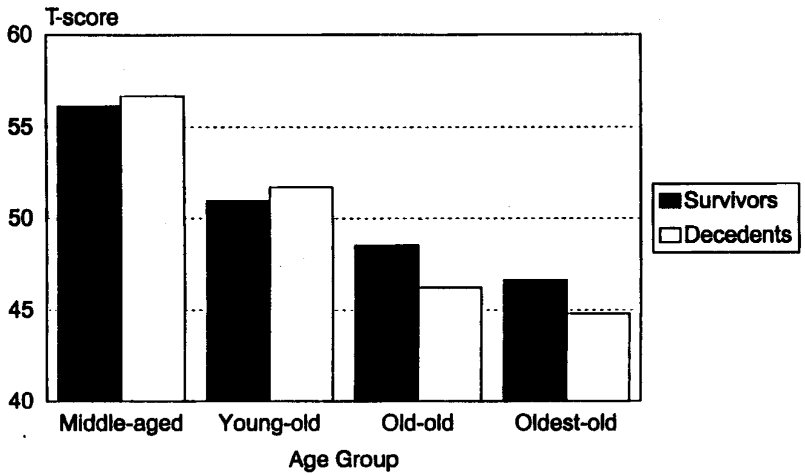

FIGURE 1 Age Group × Survivorship interaction for Verbal Meaning at last measurement.

was relatively little difference between decedents and survivors in middle-aged and young-old age groups. The middle-aged and young-old decedents had significantly higher levels of Word Fluency than their surviving counterparts, but old-old and oldest-

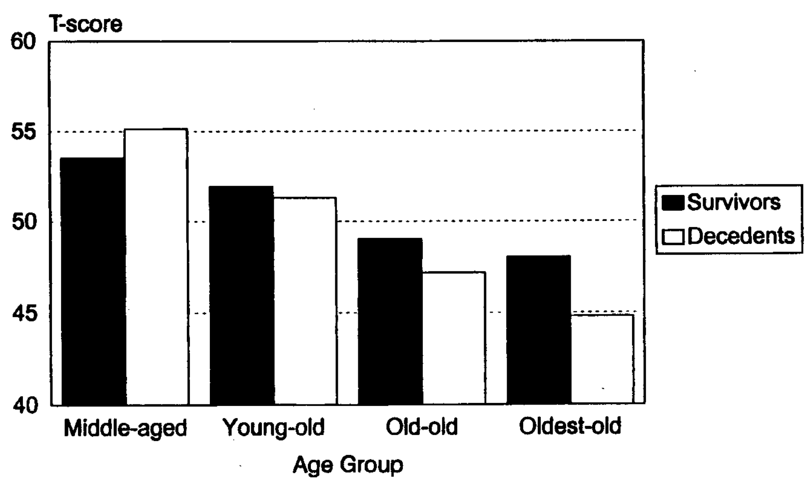

FIGURE 2 Age Group × Survivorship interaction for Numerical Ability at last measurement.

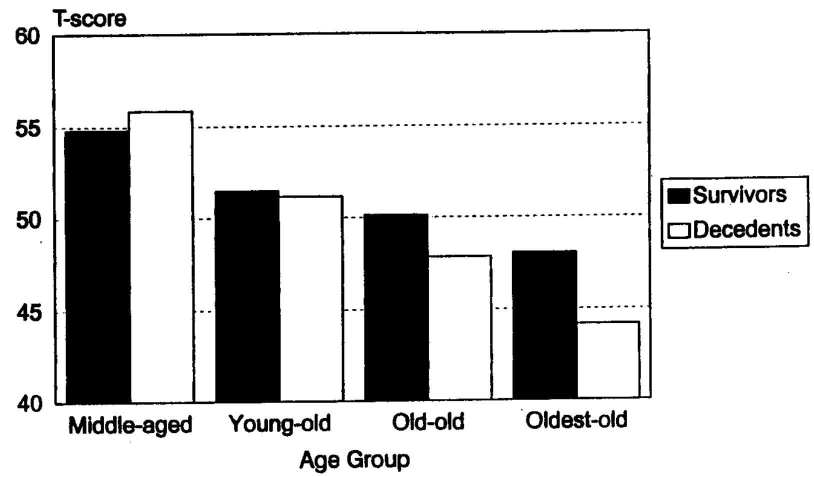

FIGURE 3 Age Group × Survivorship interaction for Psychomotor Speed at last measurement.

old decedents had significantly lower levels of performance than their surviving counterparts on this ability (Figure 4). Survivorship by gender interactions were observed for Numerical Ability and Psychomotor Speed. Surviving males had significantly higher

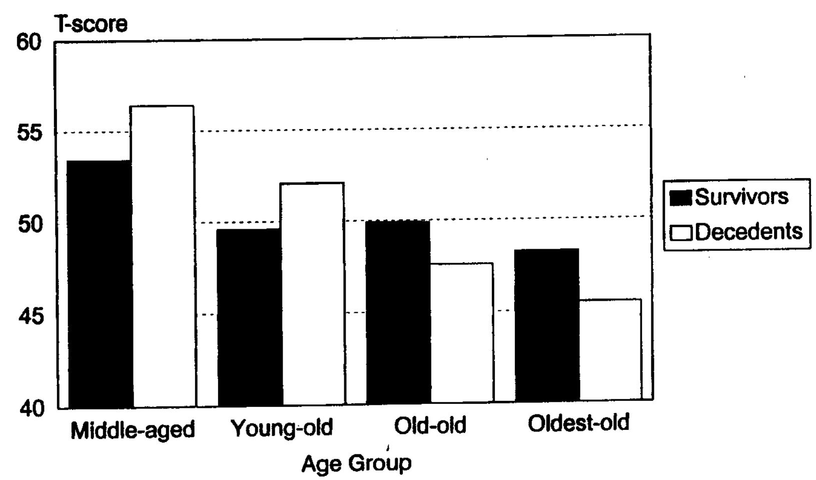

FIGURE 4 Age Group × Survivorship interaction for Word Fluency at last measurement.

levels of performance than male decedents; no significant difference between decedents and survivors were found for females.

Differences between survivors and decedents in participation was examined using a series of 2 (gender) × 2 (survival status) × 3 (number of measurements) ANCOVAs for the cognitive abilities and cognitive styles while controlling for education and age. Individuals were categorized as to whether they participated in only one measurement, two measurements, or three measurements. Only interactions between survivorship and number of measurements were of concern for these analyses. There were interactions observed for Verbal Meaning ($F(4, 1187) = 4.55$, $p < .001$), Word Fluency ($F(4, 1200) = 3.14$, $p < .01$), Spatial Ability ($F(4, 1128) = 9.13$, $p < .001$), and Inductive Reasoning ($F(4, 1187) = 6.77$, $p < .001$). Individuals with more measurements had significantly higher levels of cognitive performance. In addition, for the four abilities, Verbal Meaning, Word Fluency, Spatial Ability, and Inductive Reasoning, survivorship by measurement interactions were observable up to three measurements before the conclusion of the study. That is, decedents who had a 14-year interval between first testing and last testing still had lower levels of performance at base than their surviving counterparts.

Survival Effects for 7-Year and 14-Year Cognitive Ability and Cognitive Style Change

A series of 2 (gender) × 2 (status) × 4 (age group) repeated ANCOVAs controlling for education and baseline cognitive performance were used to examine differences in magnitude of change in cognitive function between gender, survivorship, and age groups across the last two measurement periods (7 years). Decedents declined significantly more on Verbal Meaning ($F(1, 542) = 12.04$, $p < .001$) and Psychomotor Speed ($F(1, 541) = 16.02$, $p < .001$) than did survivors over the 7-year period between individuals' last two measurements. A significant interaction between survivorship and age groups was found for 7-year change in Numerical Ability. For Numerical Ability, middle-aged decedents had significantly greater decline than their respective surviving counterparts, however old-old decedents had the greatest magnitude of change (Figure 5). Similar gender and age group main effects were observed as in the cross-sectional models.

A set of analyses similar to that used to examine rate of change across 7 years was used to measure rate of change across 14 years.

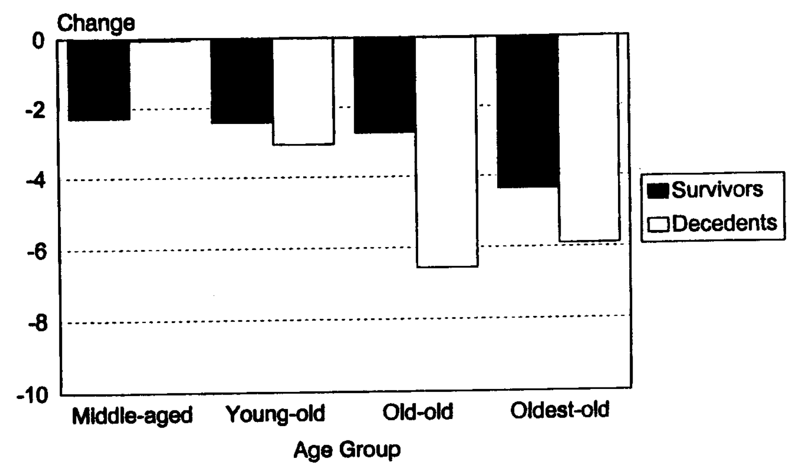

FIGURE 5 Age Group × Survivorship interaction for 7-year change on Numerical Ability.

There were no significant Age Group × Survivorship interactions; however, significant differences between survivors and decedents in magnitude of decline across the intervening 14 years were observed for Verbal Meaning ($F(1, 313) = 5.03$, $p < .007$) and Psychomotor Speed ($F(1, 311) = 6.131$, $p < .002$) after controlling for baseline performance and education levels. Decedents declined significantly more.

DISCUSSION

Our findings support the hypothesis that decedents exhibit lower levels of crystallized abilities (Verbal Meaning and Numerical Ability), visualization abilities (Spatial Ability), verbal memory (Delayed Recall), perceptual speed (Identical Pictures), and psychomotor speed at individuals' last measurement of cognitive performance and flexibility. Survival effects were observed among decedents 75 years of age and older for Verbal Meaning, Numerical Ability, and Psychomotor Speed, but not among younger adults. Surviving males also had greater levels of performance for Numerical Ability and Psychomotor Speed than male decedents; however, no differences were found for females. Greater rates of decline among decedents as compared to survivors on Verbal Meaning and Psychomotor Speed were also observed as early as

14 years before the conclusion of the study. These findings suggest that survival effects are ability-specific.

One possible explanation that could account for disagreement in the literature on whether survival effects are specific or pervasive involves the inclusion of fluid abilities in this study. Cooney et al. (1988) proposed that effects related to attrition factors, such as illness or impending death, may be obscured because fluid abilities show normative decline for almost everyone as old age is reached. No real clear differences were found on fluid abilities between survivors and decedents because both groups experienced age-related declines on these abilities. Crystallized abilities, unlike fluid abilities, remain relatively stable and decline in this ability may signal impending death (Bosworth, 1996; Cooney et al., 1988).

Significant differences on level and magnitude of change on Verbal Meaning between decedents and survivors were among the most consistent findings in this study. The present findings are similar to past studies that have found verbal ability to be uniquely sensitive to mortality (Blum, Clark, & Jarvik, 1973; Jarvik & Blum, 1971; Reimanis & Green, 1971; Siegler et al., 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, 1996; Cooney et al., 1988).

The findings of this study regarding gender and age main effects were similar to those reported previously (Schaie, 1983, 1996). To summarize these findings, observed gender effects indicated that women had lower levels on active abilities such as Spatial Ability and Numerical Ability, whereas men had lower levels of performance on passive abilities such as Verbal Meaning, Word Fluency, and Inductive Reasoning. Moreover, older individuals had lower levels of performance and greater rates of decline than younger adults.

Age Group × Survival Differences

As expected there were age differences in experiencing survival effects. No significant differences were found between middle-aged and young-old decedents and their surviving counterparts with the exception of performance on the Word Fluency task. However, the old-old and oldest-old decedents consistently had lower levels of cognitive performance and in some cases greater declines than their surviving counterparts.

The findings in this study reinforce the contention of Cooney et al. (1988) that the prediction of mortality on the basis of intellectual functioning may be more accurate in older adults. A possible explanation for these age group findings can be attributed to higher prevalence of chronic disease among older adults which is associated with deterioration prior to death. Because a majority of our middle-aged participants died more than 8 years after their last testing, it is likely that many individuals in this age group had not experienced any significant terminal change at the time of their last measurement. Support for this inference comes from analyses in which premorbid individuals (i.e., individuals who died within 2 years of their last measurement) were removed from the sample. The findings indicated that middle-aged adults maintained higher mean levels on many cognitive abilities once premorbid middle-aged adults who were likely to experience acute illnesses were removed from the sample (Bosworth, 1996).

Change in Performance

Previous research focusing on survival effects has been predominantly concerned with differences in performance levels while giving little attention to rates of change. There was only partial support for the proposition that decedents' rates of decline would be significantly greater than that of survivors. There was consistent support that decedents had greater rates of decline for both Verbal Meaning and Psychomotor Speed. For most abilities, however, it seems that what really matters for survival is not one's change from baseline performance, but one's final level of performance at the conclusion of the study. Only one measurement point was available for the majority of those who died (52%). Hence, the rate of change observed in the study sample may be an underestimation of the rate of change experienced by the total initial sample. However, there were no differences in age, education, gender proportions between those measured once or more. The only differences between those with one measurement and those with two or more is that the former had a longer time until death or the conclusion of the study ($M = 175$ months) than the latter ($M = 89$ months). It is possible that those who dropped out earlier may have had more chronic illnesses that prohibited them from continuing to participate.

Many cross-sectional findings of age-related decline are not replicated in the longitudinal analyses. Selective survival effects may offer an explanation for the observed discrepancy between cross-sectional and longitudinal findings. Riegel and Riegel (1972) suggest that older individuals may be closer to death and that the proportion of persons close to death increases with age. Longitudinal studies contain data obtained from surviving and cooperating retestees who have shown a high stability in performance (Schaie, 1996). Cross-sectional studies, however, include at various age levels, participants who are likely to die within a few years and are already exhibiting effects related to nonsurvival.

The Relationship Between Survival Effect and Terminal Change

Consistent with prior research, 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 that could bias study results. Averaging the performance of both healthy and individuals who are relatively close to death may lead to the erroneous interpretation that everyone (including healthy older adults) declines on all intellectual abilities. Because there was little indication of survival effects in younger samples, this conclusion also questions many of the results found in experimental cognitive studies where young and old individuals have been compared. Including 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 cognitive performance and increase estimated rates of cognitive decline for older samples.

Conclusions

Conducting longitudinal studies necessitates the need to examine individuals who drop out of the study as the result of mortality. One cannot assume that death strikes all persons in a random manner, although the chances of survival decrease systematically with age. Remaining older cohorts or older ages in a longitudinal study are likely to represent an increasing elite group and may mask the true trend of performance in the population. Thus, as Siegler (1975) has suggested, if mean differences are to be correctly interpreted, it is important that the number of participants at each measurement point be limited to individuals who share all data points, while nonsurvivors be evaluated to see whether there are differences.

The results of this study suggest that survival effects are age-specific and ability-specific and are observable up to 14 years before individuals' last measurements. The present findings caution against treating samples of elderly as being homogeneous and that in normative samples of elderly, there is likely to be an appreciable number of individuals experiencing survival effects that may threaten the external validity of a study. Finally, this study suggests that changes in crystallized abilities may signal impending mortality; however, future studies need to clarify the mechanisms and processes by which this relationship may occur.

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