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Relationships Among Aging, IQ, and Intracranial Volume in Alcoholics and Control Subjects

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The current article examined the relationships among aging, intelligence, intracranial volume, and brain shrinkage in alcoholics and nonalcoholic controls. Magnetic resonance imaging was used to measure intracranial and cerebral volumes in 146 subjects with alcohol use disorders and 42 comparison subjects who were not alcoholic. The authors' findings show that performance on Block Design decreases as alcoholics age, and this decrease is predicted by brain shrinkage. This is consistent with a process of cumulative brain damage related to alcohol use. However, the authors' data also show that vocabulary does not decrease with age and is correlated with premorbid brain size as measured by intracranial volume, suggesting that lower verbal ability precedes heavy alcohol use and may be a risk factor for alcoholism.

Keywords: alcoholism, brain, intelligence, aging

Within the last decade, high-resolution neuroimaging techniques have been utilized to examine changes in the neuroanatomical substrates of intelligence. Many neuroimaging studies of IQ and aging have been conducted on nonalcoholic adults or dementia patients, but few have been conducted on alcoholics. Magnetic resonance imaging (MRI) studies of brain size have shown that alcoholics have smaller brains than healthy controls have (Agartz, Shoaf, Rawlings, Momenan, & Hommer, 2003; Hommer, Momenan, Kaiser, & Rawlings, 2001). Separately conducted studies of IQ have found that alcoholics exhibit deficits on intelligence tests (Overall, Hoffmann, & Levin, 1978) and perform similarly to normal subjects 7–10 years their senior (Holden, McLaughlin, Reilly, & Overall, 1988; Ryan & Butters, 1980). These findings have generated two hypotheses regarding the nature of the relationship between aging and IQ among alcoholics (Holden et al., 1988). One is that alcohol causes brain damage, which leads to lower IQ scores. The other is that alcoholics may have lower premorbid cognitive functioning than healthy nonalcoholics have and that the rate of change due to age and/or alcohol use is not significantly different between alcoholics and nonalcoholics. The current study evaluates these hypotheses by examining the relationships among IQ, aging, and neural correlates of IQ (intracranial volume and brain shrinkage) in alcoholics and nonalcoholic control subjects.

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Intelligence, Aging, and the Brain

Studies of intelligence and aging have shown that general IQ tends to be relatively stable over the lifetime of representative samples of the population (Deary, Whalley, Lemmon, Crawford, & Starr, 2000). When components of IQ are examined with respect to the aging process, different patterns emerge (McArdle, Hamagami, Meredith, & Bradway, 2000), however. Crystallized intelligence tends to remain constant over time or increase slightly with age and then decline very late in the life span (Dixon, 2003; Giambra, Arenberg, Zonderman, Kawas, & Costa, 1995; Kaufman, 2001; Perlmutter & Nyquist, 1990; Rabbitt, Chetwynd, & McInnes, 2003). Fluid intelligence, however, declines beginning in the middle of the life span (Dixon, 2003; Kaufman, 2001; Perlmutter & Nyquist, 1990; Rabbitt et al., 2003). This suggests that it is necessary to examine the components of general IQ when examining the relationship of IQ to the aging or disease process (McArdle et al., 2000).

Neuroimaging studies have linked IQ to overall brain size, although the relationship to brain size is small (Andreasen et al., 1993; Flashman, Andreasen, Flaum, & Swayze, 1997; MacLullich et al., 2002; Rushton & Ankney, 1996; Willerman, Schultz, Rutledge, & Bigler, 1991). A recent review of neuroimaging studies of aging, brain size, and function, however, found conflicting results (Raz, 2005). On the one hand, some studies have linked structural and functional changes in the brain to cognitive performance in adults. For instance, shrinkage in brain size has been linked to lowered performance IQ scores over age (Bigler, Johnson, Jackson, & Blatter, 1995). On the other hand, other studies have found no relationship between brain volume and cognitive decline once results are adjusted for age, sex, and head size (Raz et al., 1993). Conflicting results have also been found regarding the specificity of age-related decline. Some researchers have found a relationship between frontal lobe decline and decline in fluid intelligence, whereas others have collected substantial evidence to refute this claim (for a review, see Greenwood, 2000).

IQ has also been linked to intracranial volume (Andreasen et al., 1993). Intracranial volume may be a good marker of lifetime peak

IQ, in that intracranial volume measures maximum growth of the brain, whereas the ratio of overall brain volume to intracranial volume measures degree of shrinkage (MacLullich et al., 2002; Rushton & Ankney, 1996). Both brain size and intracranial volume increase from infancy to early adolescence, but brain size decreases with age after about 20–25 years of age, whereas intracranial volume remains constant (Rushton & Ankney, 1996). The "cognitive reserve hypothesis" posits that maximum brain size is related to cognitive functioning later in life, such that people with larger brains tend to be able to sustain more damage before showing cognitive impairment (MacLullich et al., 2002; Meguro et al., 2001) or developing dementia (Mortimer, Snowdon, & Markesbery, 2003).

Intelligence, Aging, and the Brain Among Alcoholics

It is well established that alcoholics exhibit cognitive impairment compared with healthy nonalcoholic adults. Alcoholics tend to have scores on measures of IQ that are similar to those of persons many years older, suggesting accelerated mental decline among alcoholics (Blusewicz, Schenkenberg, Dustman, & Beck, 1977; Holden et al., 1988; Ryan & Butters, 1980). These indications of cognitive impairment in alcoholics are found in many areas (Overall et al., 1978), especially in areas of fluid intelligence and related areas such as "memory and learning, abstracting and problem solving, perceptual-spatial abilities, perceptual motor speed, and information processing speed" (Parsons, 1996).

Deficits in alcoholics' cognitive functioning and brain size during the aging process could be explained by two different mechanisms. The first is that alcohol causes brain damage and shrinkage, which leads to lower IQ scores. According to this hypothesis, there would be accelerated brain shrinkage, along with concomitant drops in fluid intelligence, among alcoholics. The second hypothesis, more similar to the cognitive reserve hypothesis, posits that alcoholics have premorbidly lower functioning than normal controls and that the rate of decline during the aging process is not substantially different between the two groups.

A number of studies have suggested that alcohol use damages both cognitive functioning and the brain. Bertera and Parsons (1978) found an interaction between alcoholics' age and performance on a cognitive task but no interaction among controls. MRI studies have found that length of addiction is related to shrinkage in the brains of alcoholics (Mann, Opitz, Petersen, Schroth, & Heimann, 1989). The effects of alcohol on brain shrinkage have been found to increase with age (Pfefferbaum et al., 1992; Pfefferbaum, Sullivan, Rosenbloom, Mathalon, & Lim, 1998) and alcohol consumption (Pfefferbaum et al., 1998). Although brain shrinkage can remit somewhat with abstinence (Agartz et al., 2003), recovery does not return alcoholics' brain size to that comparable to nonalcoholic controls' size (Muuronen, Bergman, Hindmarsh, & Telakivi, 1989), and the reversibility may be more pronounced in young people (Trabert, Betz, Niewald, & Huber, 1995).

In contrast, other studies have found that the rate of change due to age in the cognitive functioning of alcoholics is similar to that in normal controls. For instance, one study (Ryan & Butters, 1980) found that whereas alcoholics are more cognitively impaired than normal controls, developmental curves of alcoholics and nonalcoholic controls are parallel. Another study did not find any interaction between group and age (Cermak & Peck, 1982). A neuroimaging study found that years of drinking, lifetime alcohol consumption, and recent alcohol consumption did not moderate the relationship between alcoholism and brain shrinkage in men or women (Hommer et al., 2001).

Other Contributing Factors: Education, Cohort, and Gender Effects

Education, cohort differences, and gender may affect the relationship between aging and cognitive decline (Dixon, 2003). Education may moderate the effects of aging on IQ (Meguro et al., 2001) or lessen the chances of aging-related cognitive decline, such as dementia (Mortimer et al., 2003). Because education is related to crystallized knowledge, educational differences between cohorts in cross-sectional studies of aging may provide a confounding factor (Alwain & McCammon, 2001). Gender differences in the effect of aging on IQ may also exist. For instance, there is some evidence that women may decline earlier on fluid intelligence, whereas men decline earlier on crystallized intelligence (Schaie, 1996). These claims, however, are disputed. For instance, Rabbitt et al. (2003) found that the rate of cognitive decline was similar for people of varying levels of education and gender.

Among alcoholics, gender differences may become more prominent. There is some evidence that alcohol may cause more impairment in cognitive performance (Acker, 1985) and brain shrinkage in women compared with men and that education may not moderate the latter relationship (Hommer et al., 2001).

Method

Subjects

A total of 109 alcoholic men, 37 alcoholic women, 25 healthy men who were not alcoholic, and 17 healthy women who were not alcoholic participated in the study. Alcoholic subjects were recruited from among alcoholic patients admitted to the National Institute of Alcohol Abuse and Alcoholism (NIAAA) inpatient unit at the Clinical Center of the National Institutes of Health. Nonalcoholic comparison subjects were recruited through the Normal Subject Office of the Clinical Center of the National Institutes of Health. The study was approved by the NIAAA Institutional Review Board, and written informed consent was obtained after study procedures were completely explained. All subjects were interviewed with the Structured Clinical Interview for *DSM–III–R* (Spitzer, Williams, Gibbon, & First, 1990), and information on recent and chronic alcohol use was obtained through structured research questionnaires (Eckardt, Parker, Noble, Feldman, & Gottschalk, 1978).

All alcoholic patients met third edition revised *Diagnostic and Statistical Manual of Mental Disorders* (*DSM–III–R*; American Psychiatric Association, 1987) criteria for alcohol dependence; those who met the criteria for alcohol abuse but not alcohol dependence, or who had a history of delirium tremens or psychotic disorders, were excluded. In addition, patients who demonstrated signs of dementia or Korsakoff's disease were excluded. No subjects were thiamine-deficient at admission. The comparison subjects had no disorders meeting *DSM–III–R* criteria and reported no first-degree relatives with a history of alcoholism or problem drinking.

On the basis of history, physical examination, blood chemistry, and a negative urinary drug screen, all subjects were judged to be medically healthy. All alcoholic subjects were inpatients and were scanned at least 3 weeks after their last alcohol use. No alcoholic subject was scanned more than 5 weeks after their last alcohol use.

A social worker administered a semistructured lifetime drinking history interview to each subject. Alcohol use history was divided as needed into epochs of various use patterns based on each respondent's history, and from these epochs we calculated three drinking history parameters: (a) *age of onset of heavy drinking*, which was defined a priori as the age at which the subject reported first consuming the equivalent of 90 drinks in a 1-month period, (b) *years of heavy drinking*, defined as the cumulative total contiguous or noncontiguous months during which the subject drank 90 drinks per month (note: Because subjects often maintain this high a level of alcohol use for at least 12 consecutive months, months are summed into years), and (c) estimated *lifetime alcohol consumption* (in kg), which is a summation of all alcohol ingestion, including during periods where ingestion did not reach 90 drinks per month.

Because ethnicity has been related to IQ during the aging process (Dixon, 2003; Rushton & Ankney, 1996), only Caucasians were included in the current study. In addition, due to self-selection among persons who chose to participate in studies at NIAAA, our sample did not include enough minorities in order to conduct multivariate analyses of covariance (MANCOVAs) on their data. This limits the generalizability of our findings to Caucasians only (data for African Americans are presented in the Appendix).

Measures of Estimated Intelligence

Intelligence was estimated by two subtests of the Wechsler Adult Intelligence Scale—Revised (WAIS–R; Silverstein, 1982): Vocabulary and Block Design. These two subtests have previously been used as a "short form" of the revised Wechsler Adult Intelligence Scale to estimate IQ, with reasonably good results (Silverstein, 1982). Separately, they provide estimates of crystallized intelligence and fluid intelligence, respectively (Giambra et al., 1995; Perlmutter & Nyquist, 1990; Wechsler, 1981). In this article, we therefore also refer to Vocabulary as "estimated crystallized intelligence" and Block Design as "estimated fluid intelligence." All alcoholic subjects were tested at least 3 weeks after their most recent alcohol use.

MRI Scan Acquisition and Analysis

Subjects were scanned with a 1.5–T MRI (GE Medical Systems, Milwaukee, WI) that used a fast-spoiled gradient/recall acquisition in the steady-state sequence. We used a gapless series of high-contrast, 2-mm-thick, T1-weighted coronal images (repetition time = 25 ms, inversion time = 5 ms, and echo time = 16 ms). The images were acquired with a 256 × 256 matrix and a 240 × 240–mm field of view. Each volumetric brain consisted of 124 coronal slices with voxel size of 0.9375 × 0.9375 × 2.0 mm.

The intracranial tissue was separated from the skull on coronal sections by using a hand-controlled cursor. The intracranial volume included the cerebrum and cerebrospinal fluid (CSF) spaces covering the cortex but excluded the cerebellum and CSF of the posterior fossa. Intracranial volume was automatically segmented into CSF, gray matter, and white matter according to methods previously described and validated (Momenan et al., 1997). Cerebral volume was defined as the volume of the gray and white matter inside the skull excluding the cerebellum.

Statistical Analysis

In order to determine whether alcoholics had smaller intracranial volume than nonalcoholic controls had and confirm that alcoholics had greater brain shrinkage as measured by the ratio of cerebral volume to intracranial volume than nonalcoholic controls had, we used analysis of variance. Differences in general, crystallized, and fluid intelligence among groups were examined by using MANCOVAs. Three sets of analyses were performed. In the first set, differences in measures of intelligence between alcoholics and nonalcoholic comparison subjects and women and men were tested, with age, intracranial volume, and education entered as covariates. In the second set, ratios were created between the brain volume and intracranial volume to provide a measure of brain shrinkage. These analyses allowed us to determine how variance in intelligence was independently affected by age, diagnosis, and education, as well as brain growth and shrinkage. In the third set, analyses were conducted to determine whether comorbid cannabis use or cocaine dependence was related to intracranial volume, brain ratio, verbal IQ, or performance IQ. Brain volumes were reported in millimeters^3. In all analyses, least significant difference post-hoc tests were conducted on relevant variables. If adequate data on minorities had been available, for instance, on African Americans, 2 × 2 × 2 analyses of variance would have been appropriate, including cells based on ethnicity (data for African Americans are reported in Table A1 in the Appendix).

Results

Analyses for Intracranial Volume

Alcoholics had significantly smaller intracranial volumes than nonalcoholics had, and as expected, women had smaller intracranial volumes than did men (see Table 1). There were no significant interactions between diagnosis and gender. When age, education, and intracranial volume were used as covariates, alcoholics had significantly lower general intelligence, vocabulary, and block design than did nonalcoholics (see Tables 1 and 2). There were no significant differences for gender on any of the intelligence measures. Results of similar analyses that did not covary for age, education, or intracranial volume produced very similar significant results (data not shown). A Diagnosis × Gender interaction was significant for only vocabulary. Alcoholic men had significantly lower vocabulary than did female alcoholics and male controls (ps = .018, .001, respectively), and there was also a nonsignificant trend toward their having lower vocabulary than did female controls (p = .059). Male and female controls did not differ in vocabulary.

Within-cell regressions of the covariates on the intelligence variables are presented in Table 3. Education significantly predicted general intelligence, but age and intracranial volume did not. Age, intracranial volume, and education all significantly and independently contributed to the prediction of vocabulary. In contrast, age and education both significantly predicted Block Design score, whereas intracranial volume did not.

Table 1
Means and Standard Deviations for Alcoholic and Nonalcoholic Men and Women

Variable	Alcoholic men (n = 109)	Alcoholic women (n = 37)	Nonalcoholic men (n = 25)	Nonalcoholic women (n = 17)	All groups (n = 188)
Intracranial volume (ml)[a]	1,367 ± 106	1,290 ± 107	1,425 ± 111	1,332 ± 72	1,358 ± 112
Cerebrum to intracranial volume ratio[b]	.797 ± .031	.788 ± .025	.819 ± .033	.819 ± .028	.800 ± .031
General intelligence (IQ)	99.8 ± 9.9	103.2 ± 12.5	114.8 ± 10.5	111.8 ± 8.7	103.5 ± 11.8
Vocabulary (verbal IQ)	10.6 ± 2.2	11.8 ± 2.5	13.5 ± 1.6	12.4 ± 1.5	11.4 ± 2.4
Block design (performance IQ)	9.4 ± 2.4	9.3 ± 2.9	11.7 ± 2.8	11.6 ± 2.2	9.9 ± 2.7
Age (years)[c]	39.2 ± 9.2	42.2 ± 8.3	37.9 ± 12.1	38.3 ± 8.7	39.5 ± 9.4
Education[d] (years)	14.3 ± 2.7	15.3 ± 2.4	17.4 ± 3.2	16.3 ± 2.2	15.1 ± 2.9
Years of heavy drinking	13.1 ± 7.3	9.9 ± 6.5			
Lifetime alcohol consumption	619.2 ± 458.5	460.0 ± 352.2			
Age of onset of heavy drinking	23.6 ± 8.1	27.7 ± 9.2			

[a] Main effects for diagnosis, $F(1, 184) = 6.81$, $p = .010$; main effects for gender, $F(1, 184) = 19.63$, $p < .0001$. [b] Main effects for diagnosis, $F(1, 184) = 22.63$, $p < .0001$. [c] *ns* for both diagnosis and gender. [d] Main effects for diagnosis, $F(1,183) = 17.76$, $p < .0001$.

Both alcoholics and controls showed gains in vocabulary over the lifespan (see Figure 1). Block design, however, decreased for alcoholics with age, whereas it remained constant for controls (see Figure 2). Larger intracranial volume was associated with higher vocabulary among alcoholics but not for controls (see Figure 3). The more years of education subjects reported, the higher their intelligence scores.

Analyses for Brain Ratio

Alcoholics had significantly greater brain shrinkage than did nonalcoholics, as measured by the ratio of cerebral to intracranial volume (Table 1). Men and women did not differ in brain ratio, and there was no significant interaction between gender and diagnosis. The results for the ANCOVAs, adjusting for brain ratio, age, and education, yielded virtually the same results as the ANCOVAs that adjusted for intracranial volume, age, and education (see Table 4). There were significant differences for diagnosis on general intelligence, vocabulary, and block design. There were no significant differences for gender on any of the intelligence measures. The only significant Diagnosis × Gender interaction was on vocabulary. Alcoholic men scored significantly lower than alcoholic women, nonalcoholic men, and nonalcoholic women (ps = .029, .000, .014, respectively). Alcoholic women scored significantly lower than nonalcoholic men ($p = .021$).

Table 2
Multivariate Analyses of Covariance for Intelligence Variables With Age, Intracranial Volume, and Education as Covariates

Dependent variable and factors	$F(1, 176)$	p
General intelligence		
Diagnosis	16.90	<.001
Gender	0.64	.425
Diagnosis × Gender	0.89	.346
Vocabulary		
Diagnosis	6.84	.010
Gender	0.91	.341
Diagnosis × Gender	5.05	.026
Block design		
Diagnosis	11.72	.001
Gender	0.09	.763
Diagnosis × Gender	0.02	.884

Within-cell regressions of the covariates on the intelligence variables in the ANCOVAs using brain ratio rather than intracranial volume are presented in Table 5. Education and brain shrinkage significantly predicted estimated general intelligence. Education and age significantly predicted vocabulary. Both brain ratio and education significantly predicted block design; however, age was not significantly related to block design when brain shrinkage was taken into account. Brain ratio was positively associated with block design among alcoholics but not among controls (see Figure 4).

Analyses for Alcohol Use History

Among alcoholics, lifetime alcohol use was not significantly correlated with estimated vocabulary or block design (r = –.09, –.15, respectively). Age of onset was significantly correlated with vocabulary ($r = .27$, $p = .001$), but not block design (r = –.07).

Comparisons for Comorbid Drug Use

MANCOVAs showed that with age entered as a covariate there was no significant effect of cannabis dependence on intracranial volume, brain ratio, verbal IQ, or performance IQ among alcoholics, $F(4, 138) = 0.591$, $p = .670$. Similarly, there was no significant effect of cocaine dependence on intracranial volume, brain ratio, vocabulary, or block design among alcoholics, $F(4, 138) = 0.254$, $p = .907$. With respect to comorbid cannabis abuse and comorbid cocaine abuse, results were also not significant, Fs(4, 138) = 0.119, 0.742, p = .976, .491, respectively.

Discussion

For the purpose of discussion and to connect our results to the literature, we will relate our findings regarding vocabulary and block design to the concepts of crystallized and fluid intelligence, respectively (Kaufman, 2001). We note, however, that vocabulary

Table 3
Within-Cell Regressions of Covariates on Intelligence Variables With Age, Intracranial Volume, and Education as Covariates

Dependent variable and factors	*df*s	*F*	R^2	β	*t*	*p*
General intelligence	3, 180	20.39	.254			
Age				−.05	−0.77	.445
Intracranial Volume				.12	1.77	.079
Education				.48	7.19	<.001
Vocabulary	3, 184	33.56	.354			
Age				.15	2.42	.017
Intracranial Volume				.14	2.24	.026
Education				.51	8.34	<.001
Block design	3, 183	7.64	.111			
Age				−.22	−3.1	.002
Intracranial Volume				.07	0.93	.351
Education				.28	3.86	<.001

and block design do not exclusively measure crystallized and fluid intelligence, and therefore our use of these terms should be considered preliminary to more comprehensive data.

We found that alcoholics have smaller maximal brain growth than do nonalcoholics (indicated by smaller intracranial volume), similar to earlier reports (Daurignac et al., 2005). In addition, this report contains two new observations regarding alcoholics. First, among alcoholics intracranial volume is positively correlated with estimated crystallized intelligence. Second, brain shrinkage, in alcoholism, is correlated with estimated fluid intelligence. We also confirm numerous reports of greater brain shrinkage in alcoholism. On the basis of these results we conclude that the cognitive impairment in alcoholism is neither entirely premorbid nor entirely secondary to alcohol-induced brain damage. Rather, alcoholism-related impairment in crystallized intelligence is likely present before the onset of alcoholism. In contrast, the aspects of alcoholic cognitive impairment associated with fluid intelligence appear to be secondary to alcohol-induced brain damage.

Our conclusions are supported by the relationships we find among aging, intracranial volume, brain shrinkage, and intelligence in alcoholics and nonalcoholic controls. We know that the lower crystallized intelligence found in alcoholics compared with that in nonalcoholic controls cannot be caused by alcohol-induced brain damage because crystallized intelligence increases among both alcoholics and nonalcoholics as they age, whereas the brain shrinks with aging and heavy alcohol use. In addition to excluding brain shrinkage as a cause for lower crystallized intelligence among alcoholics, our results also suggest that the difference in estimated crystallized intelligence between alcoholics and controls precedes the onset of alcoholism. A portion of the difference in estimated crystallized intelligence between alcoholics and controls can be accounted for by differences in education and intracranial volume. Alcoholics have significantly smaller intracranial volumes and significantly fewer years of education than controls have, and both of these variables independently predict verbal IQ. Both brain growth and formal education end relatively early in the course or even before the onset of an individual's alcoholism. Thus, the

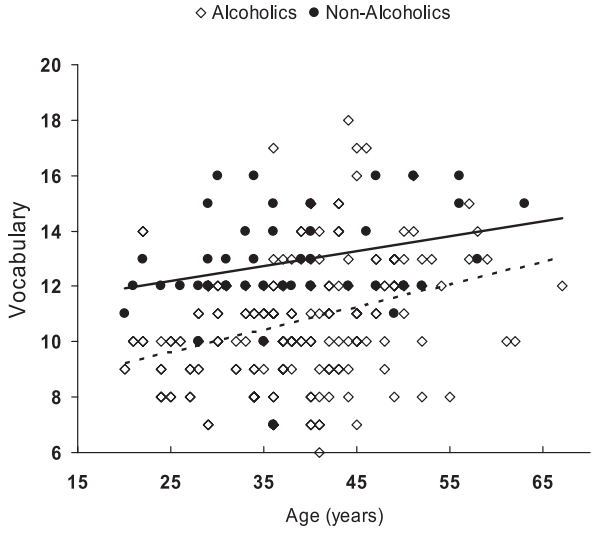

Figure 1. Changes in estimated verbal intelligence among alcoholics and control subjects over their life span.

Figure 2. Changes in estimated performance intelligence among alcoholics and control subjects over their life span.

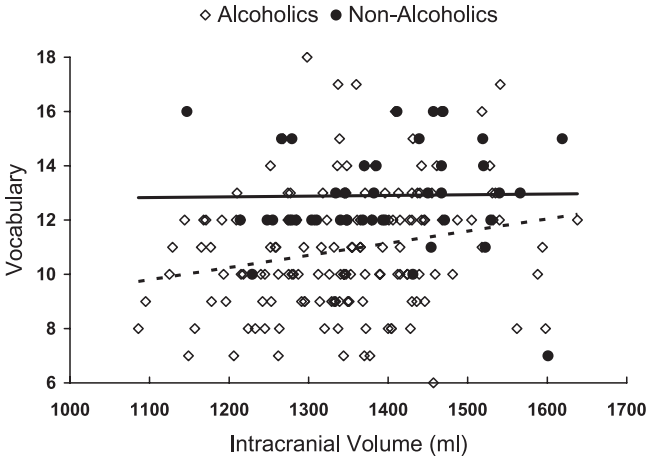

Figure 3. Relationships between intracranial volume and estimated verbal intelligence among alcoholics and control subjects.

contributions that intracranial volume and education make to crystallized intelligence likely precede the development of alcoholism. However, differences in intracranial volume and education do not completely account for lower estimated crystallized intelligence among alcoholics, because when we adjust for the variance in estimated crystallized intelligence due to age, education, and intracranial volume, differences between alcoholics and nonalcoholics remain significant. The source of the remaining variance in estimated crystallized intelligence between alcoholics and nonalcoholics remains unaccounted for but likely includes both genetic and environmental factors not reflected in brain growth and education. Genetic factors influencing crystallized intelligence could include variation in gene coding for one or more brain growth factors controlling neuronal migration and organization during development. Environmental factors might include prenatal and perinatal stress as well as early childhood physical and cognitive nurturing.

Although, like estimated crystallized intelligence, estimated fluid intelligence is significantly lower in alcoholics than among nonalcoholics, we find that estimated fluid intelligence is not significantly related to intracranial volume. Instead, estimated fluid intelligence correlates with brain shrinkage. Because the brain shrinks with heavy alcohol consumption (Bjork, Grant, & Hommer, 2003) as well as with age (Courchesne et al., 2000), and because alcoholics have significantly more brain shrinkage than nonalcoholics do, we conclude that the fluid intelligence deficit found in alcoholics is likely secondary to cumulative neurotoxic effects of excessive alcohol consumption. This is consistent with previous findings that current relative brain size plays a role in fluid intelligence (Bigler et al., 1995). Our conclusion is further supported by within-cell regression analyses of covariates, which showed that when age, education, and brain shrinkage were all taken into account, age did not significantly predict estimated fluid intelligence, whereas brain shrinkage did. As with crystallized intelligence, differences in brain shrinkage and education cannot entirely explain differences in estimated fluid intelligence between alcoholics and nonalcoholics, because when we adjust for the variance in estimated fluid intelligence due to age, education, and brain shrinkage, significant differences between alcoholics and nonalcoholics in estimated fluid intelligence remain.

Several studies of youth either at risk for or with recent onset of alcohol abuse are consistent with our conclusions that lower crystallized intelligence precedes and may be a risk factor for the development of alcoholism and that lower fluid intelligence is secondary to the toxic effects of heavy alcohol use. Twelve-year-old children of alcoholic fathers (Gabrielli & Mednick, 1983) and alcohol abusing adolescents (Moss, Kirisci, Gordon, & Tarter, 1994) were found to have significantly lower crystallized intelligence than control children had. However, in these studies, fluid intelligence in the adolescents abusing alcohol or the children at risk for alcoholism did not differ from that of controls. In addition, young men with a family history but no personal history of alcoholism have been found to have lower verbal skills than comparison young men without a family history of alcoholism (Drejer, Theilgaard, Teasdale, Schulsinger, & Goodwin, 1985; Schulsinger, Knop, Goodwin, Teasdale, & Mikkelsen, 1986).

The current study has several weaknesses. Our sample consisted of alcoholics who self-selected for treatment at NIAAA and who may have experienced more severe alcoholism than is characteristic of the general alcoholic population. This population also tends to be largely Caucasian, and thus we were not able to collect adequate data on the relationship between intracranial volume, brain shrinkage, and intelligence variables among African Americans, Hispanics, and other minorities. Future studies should extend our analyses to these minority groups, to determine whether similar relationships hold. We used two measures, Vocabulary and Block Design; however, corroboration with the full IQ scales and with other measures of fluid and crystallized intelligence would strengthen the results of the study. Additionally, the cross-sectional design of the study could have biased the results because of possible generational differences in IQ. However, there is evidence that such effects may be small to nonexistent (Kaufman, 2001).

Another limitation of our study is the inherent difficulty with the use of education as a variable, as it is possible that alcoholism leads to a lower level of education obtained. Ideally, longitudinal studies are necessary to determine whether premorbid intelligence, cognitive decline, age of onset, or socioeconomic and emotional difficulties related to alcoholism contribute substantially to the lower levels of education found among alcoholics.

Table 4
Multivariate Analyses of Covariance for Intelligence Variables With Age, Brain Ratio, and Education as Covariates

Dependent variable and factors	$F(1, 176)$	p
General intelligence		
Diagnosis	14.02	$< .001$
Gender	0.04	.841
Diagnosis × Gender	0.97	.327
Vocabulary		
Diagnosis	10.34	.002
Gender	0.01	.920
Diagnosis × Gender	4.72	.031
Block design		
Diagnosis	6.63	.011
Gender	0.01	.927
Diagnosis × Gender	0.00	.948

Table 5
Within-Cell Regressions of Covariates on Intelligence Variables With Age, Brain Shrinkage, and Education as Covariates

Dependent variable and factors	*df*s	*F*	R^2	β	*t*	*p*
General intelligence	3, 180	21.84	.267			
Age				.07	0.86	.392
Brain Shrinkage				.20	2.53	.012
Education				.49	7.49	.000
Vocabulary	3, 184	31.06	.336			
Age				.15	1.98	.049
Brain Shrinkage				.01	0.12	.906
Education				.53	8.69	.000
Block design	3, 183	12.33	.168			
Age				−.04	−0.41	.685
Brain Shrinkage				.31	3.67	.000
Education				.27	3.97	.000

Note. Brain Shrinkage = the ratio of cerebral volume to intracranial volume.

A final weakness of the study is that intelligence was measured in alcoholics after 3 weeks of detoxification. It is possible that alcoholics' block design performance may still improve even after 3 weeks of sobriety and that the correlation between brain shrinkage and fluid intelligence actually represents a correlation between brain shrinkage and cognitive recovery time. However, although there is some evidence that recovery of fluid intelligence can occur after detoxification (McLachlan & Levinson, 1974), it has been shown that improvement usually occurs within a short time span after detoxification (Clarke & Haughton, 1975) and deficits still can be found from 10 weeks to 1 year later (Clarke & Haughton, 1975). Because our study did not examine the relationship of various cognitive functions related to impulsivity and executive function, we cannot comment on how these aspects of cognition relate to brain growth and shrinkage in alcoholism or the extent to which they can be considered pre- or postmorbid. Despite these weaknesses, we believe our results provide strong support for the idea that cognitive impairment in alcoholism is a mixture of premorbid differences in crystallized intelligence and postmorbid deterioration in fluid intelligence.

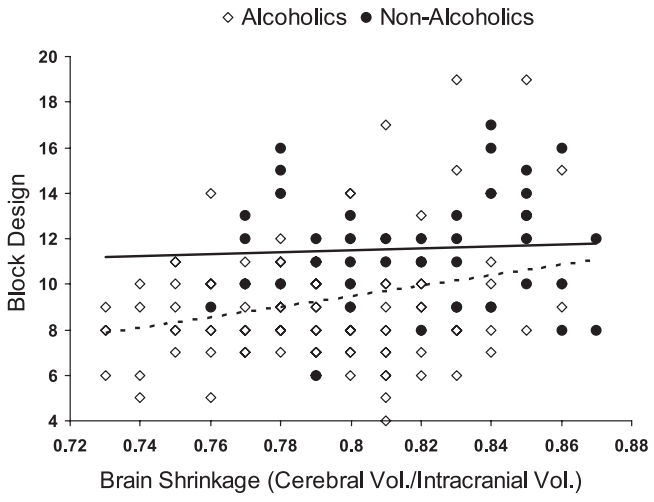

Figure 4. Relationships between brain ratio and estimated performance intelligence among alcoholics and control subjects.

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Appendix

Means and Standard Deviations for African American Sample (Not Included in Analyses)

Variable	Alcoholic men (n = 21)	Alcoholic women (n = 7)	Nonalcoholic men (n = 2)	Nonalcoholic women (n = 5)	All groups (n = 35)
Intracranial volume (ml)	1,296 ± 113	1,238 ± 106	1,198 ± 61	1,215 ± 52	1,267 ± 106
Cerebrum to intracranial volume ratio	.793 ± .034	.809 ± .038	.828 ± .031	.844 ± .015	.806 ± .037
General intelligence (IQ)	92.2 ± 8.4	98.7 ± 6.9	97.5 ± 7.8	103.4 ± 9.5	95.4 ± 9.0
Vocabulary (verbal IQ)	9.4 ± 1.8	10.4 ± 1.5	9.5 ± 0.7	10.6 ± 1.9	9.8 ± 1.8
Block design (performance IQ)	7.8 ± 2.0	9.1 ± 1.2	9.5 ± 3.5	10.6 ± 2.1	8.6 ± 2.1
Age (years)	42.1 ± 8.8	36.7 ± 5.8	33.5 ± 6.4	26.2 ± 5.7	37.4 ± 9.7
Education (years)	13.2 ± 2.1	14.6 ± 1.7	13.8 ± 0.4	16.8 ± 2.3	14.3 ± 2.6
Years of heavy drinking	11.7 ± 9.7	6.6 ± 7.7			
Lifetime alcohol consumption	632 ± 538	436 ± 619			
Age of onset of heavy drinking	23.12 ± 7.1	33.0 ± 4.7			

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