Stroop interference

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Stroop Interference:
Aging Effects Assessed with the Stroop Color-Word Test

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*A large, cross-sectional aging investigation of
performance on the Stroop Color-Word Test (SCWT)
was carried out. Subjects were 247 volunteers, ages
20–80 in seven age levels. Although all subjects
thought themselves to be normal and healthy, a post
hoc division could be made on the basis of biological
life events (BLE). BLE are mild biological or
environmental factors, such as repeated experiences of
general anesthesia, that can hamper optimal brain
functioning. Apart from the anticipated age effects,
performance was poorer in subjects who had
experienced one or more BLE: The slowing due to BLE
was comparable to the effect of age, especially on the
task involving language interference in color-naming.
Education had a significant effect on performance:
More highly educated subjects performed better than
less educated subjects. No sex differences were
observed. These findings replicate observations made
with other tests in parallel studies. They are also in
line with several other studies reporting interactions
between the effects of aging and physical fitness. This
study questions some of the validity of cognitive aging
research, as our data suggest that screening for BLE
as age-extrinsic factors in nondiseased subjects can
reduce many of the performance deficits usually
ascribed to aging per se.*

The Stroop Color-Word Test (SCWT; Stroop, 1935) is a well-known
test used to assess the ease with which subjects can change perceptual

209

sets to conform to changing task requirements (Lezak, 1983). Several different versions are available, but the test typically consists of three subtests. Briefly, in Subtest I, 10 rows × 10 columns of color names (*red, blue, green,* and *yellow*) are printed in black on white cardboard. The time needed to read the color names aloud is registered. In Subtest II, the same number of correspondingly colored patches are printed (the colors have to be named). In Subtest III, the color names are printed in incongruously colored ink. For instance, the word *green* can be printed in red. The color of the ink has to be named.

The most interesting feature of the SCWT for the present study is that it enables a reliable estimate of the susceptibility to interference if the time needed for Subtest III is related to the time needed for Subtests I and II. There are different ways of administering the test (Lezak, 1983). The procedure for the present study is described in the method section.

The SCWT is used for a wide variety of purposes. Neil and Westberry (1987) have studied the nature of selective attention and interference by cognitive noise with a computerized version of the test. It was concluded that selective inhibition is the time-consuming factor underlying the interference experienced in Subtest III. To study prefrontal cortical functioning in reading-disabled children, Kelly, Best, and Kirk (1989) used the test to discriminate between frontal and posterior cognitive functions. It was found that selective and sustained attention were most impaired. Smith and Miles (1986) found that performance was poorer after lunch than before.

There are little data on cognitive aging as it affects performance on the SCWT. To date, only two studies have related the Stroop phenomenon to adult aging. Comalli, Wapner, and Werner (1962) found no significant age-related decline in speed in Subtest I (reading) in subjects ages 17–80 years. Color naming in Subtest III was markedly slowed down, but only in subjects over age 65. Cohn, Dustman, and Bradford (1984) reported similar findings with subjects ages 21–90 years. These authors observed no significant slowing in reading and reading with color interference. A steady decline in speed was detected in Subtest II (color naming) and a sharp increase in the effect of word interference in Subtest III.

In the last decade, several authors have argued that the age-related cognitive decline is not a monocausal, unitary concept. For instance, Rabbitt (1986) showed that the smooth average decline in cognitive performance often reported in cross-sectional studies could be because older age groups contain more subjects who perform poorly as a result of factors extrinsic to age. A substantial group of elderly subjects performed just as well as healthy young individuals. Arbuckle, Gold, and Andres (1986) found that changes in memory performance correlated less well with age

than with contextual variables such as education, intellectual activity, or personality scores. Craik, Byrd, and Swanson (1987) also reported this. Perlmutter and Nyquist (1990) found that self-reported physical and mental health accounted for a significant proportion of the variation in performance, particularly in older adults. M. F. Elias, Elias, and Elias (1990) discussed methodological issues in the study of interactions between health and age regarding behavioral changes and cited data on various diseases such as cardiovascular disease, diabetes, or Parkinson's disease. They rightly stated that the amount of information on the interaction between age and health has exploded in the last few years. However, in our view, too little attention has been paid to what Rowe and Kahn (1987) termed "usual," nondiseased aging, as it is affected by mild health-related factors.

The decline in cognitive functioning with age may be continuous, but this continuum may be disrupted or accelerated in many individuals by what we term *biological life events* (BLE). By definition, BLE are mild biological or environmental factors that can hamper the optimal functioning of the brain (Houx, Vreeling, & Jolles, 1991b). We proposed recently that a thorough selection of subjects based on BLE will greatly reduce the magnitude of the age-related decline in performance (Houx, Vreeling, & Jolles, 1991a). Thus, BLE should be seen as an important source of interindividual variation, as are intelligence, educational level, and other factors mentioned by researchers in the field of aging (e.g., Salthouse, Kausler, & Saults, 1988, mentioned occupational status or hours per week spent reading). Examples of BLE are exposure to organic solvents or other neurotoxic factors (Hartman, 1988) and repeated mild head injuries without direct cognitive sequelae (Binder, 1986). Houx, Vreeling, and Jolles (1989, 1991a) found enhanced age-related declines in the speed of memory scanning, verbal memory, memory span, and motor planning in normal, healthy subjects who had experienced one or more BLE.

Haxby et al. (1986) have presented data that are consistent with the notion that BLE interact with age. In elderly men who had passed a "rigorous health screening," these authors observed a much smaller age effect on visual memory than is usually reported. To date, as is evident from several authoritative handbooks on aging (e.g., Birren & Schaie, 1985, 1990; Charness, 1985), little or no attention has been paid to the direct relationship between the BLE that potentially result in brain dysfunction on the one hand and those that result in cognitive dysfunctions on the other.

In the present study, we investigated the possible interactions of aging and BLE in their effect on reading speed, attention, and interference susceptibility, as assessed with the SCWT.

Table 1. Biological Life Events

1. Present or past treatment by a neurologist for transient ischemic attack, epilepsy, migraine, meningitis, encephalitis, mild closed head injury, etc.
2. Present or past treatment for diseases with possible repercussions on the brain (e.g., renal dysfunction, diabetes mellitus, and thyroid dysfunction).
3. More than three concussions, or one with a Parent Teacher Association of more than 1 hr.
4. Administration of general anesthesia more than three times or one time for more than 3 hrs.
5. Use of medication that affects driving ability or consciousness.
6. Alcohol abuse (more than 35/21 glasses per week for men/women, respectively).
7. Other neurotoxic factors, such as exposure to organic solvents or substance abuse.
8. Present (or fewer than 5 years ago) treatment by a psychiatrist.
9. Complications at birth or developmental problems in early childhood.

Note. Adapted from Houx, Vreeling, and Jolles (1991b).

It appeared that of 31 subjects age 20 years, 9 had experienced one or more BLE, and this ratio increased for every successive age group (see Table 2 for the exact numbers of subjects). Because the number of participants in the elderly age groups who reported having experienced one or more BLE far exceeded the number who did not, not all of the elderly BLE subjects participated in the actual testing. This was done in order to keep the number of subjects in the age groups roughly the same.

Care was taken to balance the level of education in each Age × Sex subgroup. For this purpose, we used a Dutch scoring system adapted from Verhage (1964): a 7-point scale, ranging from *primary education not finished* (1) to *master's degree* (7). The advantage of this scoring system over counting the years of scholastic education is that qualitative aspects of education, which reflect intellectual ability, are also taken into account. For the present study, the 7-point scale was condensed to two levels: 1–4 (less educated) and 5–7 (more educated). All subjects were paid for their participation in the experiment.

Administration of the Stroop Color-Word Test

For Card I, the subject is requested to "read the color names row by row, as fast as you can, without making mistakes." The time needed to complete the whole card is recorded with a stopwatch. For the second subtest (Card II), the instruction is to "name the colored patches." The third trial (Card III) involves naming the color of the ink the words are printed in, without paying attention to the word itself. A fourth trial is often used to measure the time needed to read the color names from Card

METHOD

Subjects

Subjects were recruited by means of advertisements in local newspapers and from a local brass band, sports club, and old people's home. We explicitly asked for normal, healthy volunteers. Subjects were screened over the telephone: Only those applicants who regarded themselves as being healthy, normal, and not in need of help took part in the investigation. Persons who, on being asked, reported major brain damage by trauma, stroke, disease, or poisoning or who reported a major psychiatric illness known to be characterized by cognitive deficits were excluded from the study. Two hundred fifty-six subjects were selected. More than 100 applicants were not selected because, although they judged themselves to be healthy, their self-reported medical history revealed major diseases or events with repercussions on the brain.

The subjects were screened again before the actual testing. Nine subjects did not pass this screening: Six subjects were demented, having scores of less than 24 on the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), 2 subjects appeared to have had major head injuries resulting in persistent cognitive dysfunctions in their medical histories (available to the examiners), and 1 subject had been treated for a brain tumor. Thus, we had a large group of subjects without any a priori likelihood of brain dysfunction or cognitive dysfunctions attributable to a major neurological or psychiatric illness.

Subject Assignment to Groups

The 247 subjects were subjected to a semistructured and semiquantitative interview concerning BLE prior to actual testing. Nine categories of BLE were identified, varying from minor neurological dysfunctions, repeated mild head trauma, or repeated administrations of general anesthesia to complications at birth, such as perinatal hypoxia (see Table 1 or Houx et al., 1991, for a complete description). Each BLE was scored as either present or absent. Subjects who had experienced one or more BLE were assigned to a separate BLE × age group. Subjects who had not experienced any of the BLE were assigned to a corresponding healthy group for that age. There were 2 × 7 discontinuous age groups, with mean ages ranging from 20 to 80 years. Irrespective of BLE, the mean ages of the groups were 20.1 $(SD = 1.8)$, 30.4 $(SD = 1.7)$, 39.9 $(SD = 2.0)$, 49.8 $(SD = 1.8)$, 59.8 $(SD = 2.1)$, 69.7 $(SD = 2.1)$, and 79.1 $(SD = 2.0)$. About half of the subjects in each age group were male.

Table 2. Age and Education of the Experimental Groups with and Without Biological Life Events (BLE)

	±20 yr		±30 yr		±40yr		±50 yr		±60 yr		±70 yr		±80 yr	
	Age	Education	Age	Education	Age	Education	Age	Education	Age	Education	Age	Education	Age	Education
BLE absent ($n = 150$)														
N	22		20		22		20		20		25		21	
Range	17–23	4–7	27–33	3–7	37–43	3–6	47–53	3–7	57–63	2–6	67–73	2–7	77–81	2–7
M	20.27	5.36	30.45	5.15	39.95	4.73	49.65	4.75	60.15	4.60	69.72	4.84	78.62	4.29
SD	1.91	1.26	1.82	1.23	1.73	1.08	1.87	1.21	2.21	1.27	2.01	1.34	1.24	1.71
BLE present ($n = 97$)														
N	9		9		12		15		15		17		20	
Range	17–22	3–7	27–32	3–6	36–43	2–6	47–53	2–7	57–63	2–7	67–73	2–6	77–83	1–7
M	19.56	4.67	30.33	5.22	39.75	4.58	50.07	4.53	59.40	4.07	69.44	4.00	79.32	3.42
SD	1.67	1.41	1.73	1.09	2.56	1.31	1.87	1.46	1.99	1.44	2.28	1.65	2.43	1.68

Note. Educational level was based on Verhage's (1964) system of scoring education.

III. Almost invariably, Subtest I (reading) takes the least time (less than 1 min). Color naming is a much less common activity than reading. Consequently, Subtest II takes longer to complete (about 1 min). Subtest III also consists of this same uncommon activity, but this is interfered with by verbal information that has to be ignored. Conversely, reading color names, interfered by incompatibly colored ink (the fourth subtest) is much easier, because the color information is easily ignored. This trial does not take much more time than Subtest I (Cohn et al., 1984) and is thus not very informative. Because of this, it was not included in the present study.

By subtracting the average duration of Trials I and II (basic speed) from that of Subtest III, one obtains the delay caused by the interference of two activities. This delay can be expressed as a proportion, by dividing it by the average of Trials I and II.

Other Investigations

A complete neurological examination, including primitive and other (pathological) reflexes, was part of the procedure (Vreeling, Verhey, Houx, & Jolles, 1988). All subjects then underwent a neuropsychological investigation in which the SCWT was administered in addition to other tests. The results of the other tests are discussed elsewhere (Houx et al., 1989, 1991a, 1991b). The whole procedure took about 2 hr.

Statistics

Total times taken to finish the subtests were tested by means of a repeated measures analysis of variance (ANOVA) with age (seven levels), presence or absence of BLE (two levels), sex (two levels), and education (two levels) as main between-subjects variables and subtest as the within-subject variable. This design was also used to analyze the numbers of errors and spontaneous corrections. For analysis of the extra time needed to complete Subtest III relative to Subtests I and II, expressed by the formula (III − ½(I + II))/½(I + II), a separate ANOVA was performed, with identical between-subjects variables. Alpha levels of 5% were taken to denote statistical significance.

RESULTS

The mean total times to finish each subtest are summarized in Figure 1. Mean performance per Age × BLE group is given in Table 3. There were substantial effects of group age and BLE. The ANOVA showed significant overall between-subjects effects of age, $F(6, 217) = 23.28$,

Table 3. Mean Performance on Subtests I–III of the Stroop Color-Word Test of Subjects with and Without Biological Life Events (BLE)

Age group	Total time			% interference	Spontaneous correct			Errors		
	I	II	III		I	II	III	I	II	III
BLE absent										
±20 yr (n = 22)										
M	40.1	51.1	77.3	71.1	0.2	0.5	1.6	0.1	0.0	0.4
SD	7.5	9.9	11.4	14.4	0.5	0.8	1.2	0.3	0.2	0.9
±30 yr (n = 20)										
M	39.6	54.0	80.8	72.6	0.1	0.8	1.1	0.1	0.1	0.3
SD	5.9	7.9	13.8	17.7	0.4	1.0	1.0	0.3	0.4	0.8
±40 yr (n = 22)										
M	39.9	52.7	86.4	85.3	0.0	0.6	1.3	0.0	0.2	0.3
SD	4.8	9.4	20.9	28.2	0.2	0.7	1.5	0.0	0.5	0.6
±50 yr (n = 20)										
M	37.0	50.1	81.3	88.1	0.2	1.1	1.4	0.1	0.3	0.3
SD	4.8	9.1	11.7	21.9	0.4	1.1	1.4	0.3	0.5	0.7
±60 yr (n = 20)										
M	41.5	56.1	93.6	92.5	0.1	1.5	1.4	0.1	0.1	0.4
SD	4.3	6.8	16.5	31.8	0.3	1.0	1.6	0.4	0.4	0.8
±70 yr (n = 25)										
M	41.3	56.4	99.5	98.5	0.3	1.5	1.6	0.3	0.3	1.8
SD	4.1	5.6	20.7	37.0	0.7	1.6	2.0	0.6	0.7	2.7
±80 yr (n = 21)										
M	44.1	61.6	105.5	100.3	0.3	1.3	2.5	0.3	0.5	0.8
SD	5.5	8.3	13.9	19.0	0.6	1.0	2.4	0.6	0.8	1.4

BLE present

	1	2	3	4	5	6	7	8	9	10
±20 yr (n = 9)										
M	38.2	52.8	82.3	79.9	0.1	0.8	0.9	0.0	0.0	0.1
SD	4.2	7.2	19.9	33.8	0.3	1.0	1.4	0.0	0.0	0.3
±30 yr (n = 9)										
M	41.1	52.8	91.4	94.8	0.3	0.4	0.9	0.0	0.0	0.4
SD	6.1	10.1	23.1	41.3	0.5	0.5	1.2	0.0	0.0	1.0
±40 yr (n = 12)										
M	40.1	51.7	92.8	103.0	0.1	0.8	0.8	0.0	0.3	0.3
SD	4.2	6.6	16.2	34.0	0.3	0.7	1.2	0.0	0.7	0.4
±50 yr (n = 15)										
M	41.2	57.4	92.3	88.1	0.1	0.8	0.9	0.1	0.0	0.1
SD	4.1	8.9	10.0	18.2	0.5	0.8	1.6	0.2	0.0	0.2
±60 yr (n = 15)										
M	46.3	58.6	102.2	88.7	0.3	1.8	1.5	0.1	0.4	1.4
SD	8.5	6.7	19.0	41.0	1.0	1.9	1.7	0.5	1.0	2.9
±70 yr (n = 18)										
M	43.1	63.2	138.1	164.5	0.2	2.2	3.5	0.9	0.6	3.4
SD	4.9	11.4	36.2	87.2	0.5	2.0	3.7	1.3	0.9	5.2
±80 yr (n = 19)										
M	50.9	73.3	181.1	193.3	0.3	1.9	3.3	0.7	1.2	5.2
SD	6.8	19.9	45.6	58.6	0.5	1.3	1.7	0.9	1.6	5.6

Note. Percent interference is the extra time needed to complete Subtest III relative to Subtests I and II: $(III - \frac{1}{2}(I + II)) / \frac{1}{2}(I + II) * 100\%$.
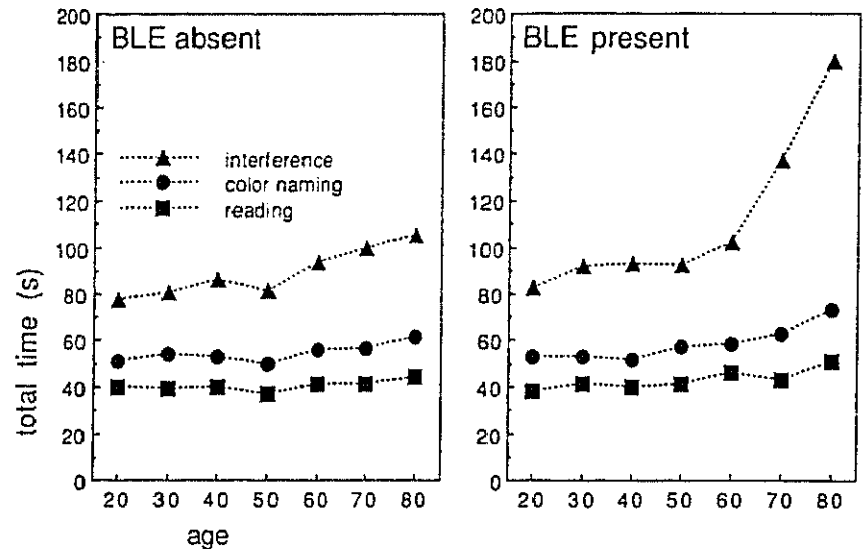
217

Fig. 1. Total time needed to complete the three Subtests of the Stroop Color-Word test as a function of age and the presence or absence of biological life events (BLE).

$p < .001$; BLE, $F(1, 217) = 34.72$, $p < .001$; and level of education, $F(1, 217) = 15.20$, $p < .001$. Sex had no effect ($F < 1$ for all parameters). It can be concluded that older age groups were generally slower to finish the whole test. Also, the BLE-affected group was slower than the BLE-unaffected group. Lastly, less educated subjects were slower than more highly educated subjects. Only one interaction between two between-subjects variables was significant: Age × BLE, $F(6, 217) = 4.82$, $p < .001$. This indicates that the performance gap between BLE-affected and BLE-unaffected subjects widened with increasing age. Age and education did not interact $F(6, 217) = 1.38$, ns, which means that less educated subjects did not show larger age effects than did their more educated age mates. BLE and education did not significantly interact either, $F(1, 217) = 3.62$, ns, which can be taken to indicate that the effect of BLE was not enhanced in less educated subjects. No set of three between-subjects effects showed a significant interaction ($Fs < 1$).

Regarding the effects of the within-subject variables (Subtests I, II, and III), there was a large overall effect on the total time needed to finish the subtest, $F(2, 434) = 1339.60$, $p < .001$. All subjects took longer to complete Subtest II than Subtest I and took longer to complete Subtest III than Subtest II. As can be deduced from the interaction of this effect with age, $F(12, 434) = 21.05$, $p < .001$, older subjects needed extra

time for color naming, and still more time when they experienced color-word interference. The same interaction was found between repeated measures and BLE, $F(2, 434) = 36.71, p < .001$. There was an immense difference between color-word interference effects in BLE-affected and BLE-unaffected subjects. The performance of less educated subjects suffered more from the increasing subtest difficulty than did that of the more highly educated subjects: For the interaction between the repeated measures and education, $F(2, 434) = 5.97, p < .01$.

Two complex interactions were also significant. First, there was a marked Age × BLE × Repeated Measures interaction, $F(12, 434) = 7.03, p < .001$ (Figure 1). Elderly BLE-affected subjects showed by far the largest effect of subtest difficulty. Second, the Age × Education × Repeated Measures interaction $F(12, 434) = 1.83, p < .05$, showed that having a lower level of education further enhanced the effect of age on the susceptibility to interference. There was no significant BLE × Education × Repeated Measures interaction, $F(2, 434 = 2.20, ns$. The Age × BLE × Education × Repeated Measures interaction was not significant either, $F(12, 434) = 1.21, ns$.

The color-word interference effect increased significantly with age, $F(6, 217) = 20.82, p < .001$, and the presence of BLE, $F(1, 217) = 39.65, p < .001$, and decreased with level of education, $F(1, 217) = 6.71, p < .01$. These data support the conclusions drawn from the ANOVAs with the repeated measures. The only significant interaction was between age and BLE, $F(6, 217) = 7.37, p < .001$, which showed that BLE-affected subjects experienced the most color-word interference.

Accuracy roughly decreased in older age groups, $F(6, 217) = 7.80, p < .001$; in the BLE-unaffected group, the average number of uncorrected color naming errors in Subtest III increased from 0.4 in subjects ages 20–30 years to 1.3 in subjects ages 70–80 years; in the BLE-affected group, these values were 0.3 and 4.3, respectively. For the main effect of BLE, $F(1, 217) = 4.82, p < .05$. Less educated subjects were also less accurate, $F(1, 217) = 5.70, p < .05$, than were the more highly educated subjects. None of the interactions among the between-subjects effects on the number of errors was statistically significant.

More errors were made in each successive subtest, $F(2, 434) = 17.44, p < .001$. This increase interacted with age, $F(12, 434) = 3.50, p < .001$; with BLE, $F(2, 343) = 3.46, p < .05$; and with education, $F(2, 434) = 3.87, p < .05$. None of the complex interactions with two or more between-subjects variables was significant.

The number of corrected errors was affected only by age, $F(6, 217) = 5.87, p < .001$. Other between-subjects effects (main effects or interactions) were not significant. There was a repeated measures effect of increasing task difficulty on the number of spontaneous corrections, $F(2,$

434) = 79.72, $p < .001$, which also interacted with age, $F(12, 434) =$ 3.21, $p < .001$, and education, $F(2, 434) = 3.14$, $p < .05$, but not with BLE.

From the data just presented, little can be said about the influences of the BLE, as mentioned in Table 1, individually. The prevalence of most of the BLE was rarely higher than 2 or 3 in most age groups. Furthermore, because most of the BLE were scored either present or absent, little information was gained about their relative importance. Of those BLE that could be quantified (numbers of closed head injuries and narcoses sustained and alcohol consumption per week) the correlations rarely exceeded .10, which is not statistically significant. Part of the individual variation in test performance can be explained by the number of BLE to which subjects had been exposed. A Pearson's r of .29 ($p < .001$) was found for the correlation between this variable and time needed for Subtest III; for subject age, r was .55 ($p < .001$). The amount of extra time needed for Subtest III relative to Subtests I and II correlated with the number of BLE ($r = .28$, $p < .001$) and with subject age ($r = .46$, $p < .001$).

DISCUSSION

The objective of the present study was to assess whether BLE could account for a substantial amount of variation observed in the performance of nondiseased aging subjects on the SCWT. Evidence was found to support the hypothesis that BLE play a significant role in age-associated decline in performance, comparable to that of calendar age. Adults over a broad range of age categories were tested. After correction for BLE, the observed age effect was much smaller than in the whole sample. Conversely, subjects affected by BLE showed a much more pronounced age-related decline in performance than did their unaffected age peers. This was especially so in the subtest involving color-word interference. Significant interactions were found among the effects of age, BLE, and task requirements. No sex differences were found. A very slight decrement in basic reading speed with age was observed. Older subjects were much slower at color naming than were younger subjects, but a striking age effect was found as to language interference. Elderly subjects were slowed down considerably by the irrelevant verbal information that came with the color that was to be named. The most remarkable finding, however, was that in the group of 80-year-olds, BLE-unaffected subjects needed half the time that their BLE-affected counterparts needed to complete Subtest III.

Golden (1974) observed that women performed the SCWT better than men. This was not replicated in the present study. Neither did we find

any changes in the trade-off between speed and accuracy. Several authors (see Botwinick, 1977, for a review) have maintained that as people grow older, they become more cautious and therefore slower but more accurate. We have been unable to confirm these claims in a number of studies (Houx et al., 1991a, b). It might be that in situations not confined to the laboratory, for example, driving a car, a strategical shift occurs to emphasize accuracy rather than speed in the elderly.

The SCWT appears to be very sensitive to age-related slowing or interference effects. Several authors have sought to detect the cognitive source of the Stroop phenomenon (Doehrman, Landau, & O'Connel, 1978; Virzi & Egeth, 1985). Whatever the nature of the delay found in all subjects, it is apparent that focused attention is disrupted when some perceptually salient, but irrelevant, aspect is added to the stimulus. We found that interference increased from 70% in subjects age 20 to 100% in 80-year-old BLE-unaffected elderly. This increment is very small compared with the age trend observed in BLE-affected elderly subjects, some of whom showed interference effects of well over 200%.

Rigorous screening for BLE appears to reduce greatly the observed age effects. These findings are incompatible with Salthouse, Kausler and Saults's (1990) report that they found no reduction in age trends in cognitive functioning after correction for self-perceived health. Their measures of health status being "crude," as they put it, they deemed it premature to conclude that the relations between age and cognition were unaffected by health status. Earlier, they had found that age trends in the same sample of subjects were relatively independent of an assortment of background variables, such as health, intellectual activities, and occupational status (Salthouse et al., 1988). Our findings are very much in line with those of Perlmutter and Nyquist (1990), who stated that "the patterns of correlational analyses suggested that health probably accounts for a greater portion of individual differences in older than younger adults' intelligence performance" (p. 154). Specific health-related variables have been studied for their relation to cognition. For instance, M. F. Elias, Robbins, Schultz, and Pierce (1990) found significant effects of blood pressure for a number of neuropsychological parameters, and even some Age × Hypertension interactions, although these were not found in a longitudinal aging study (W. F. Elias, Schultz, Robbins, & Elias, 1989).

Our results are consistent with some of our earlier studies on performance in other neuropsychological tests, such as free recall and recognition of verbal material (Houx et al., 1989, 1991a) and speed of memory scanning (Houx et al., 1991b). We observed that performance tended to show a lower correlation with the number of BLE than with age, contrary to Perlmutter and Nyquist's (1990) claim. All correlations between performance and number of BLE were significant, however. Thus, although

age is a better predictor of test performance than is the number of BLE, health-related factors should be taken into account when considering cognitive performance.

It is clear from the present study (and from other studies by ourselves and others) that controlling for BLE in the assignment of subjects to experimental groups has far-reaching consequences for the outcomes of aging research. In the first place, age effects are much smaller in subjects without BLE than in an unselected sample. This implies that the average aging subject is not necessarily the most successfully aging subject (see Rowe & Kahn, 1987, for a review). Furthermore, the likelihood of experiencing one or more BLE increases with age. Whether cognitive aging enhanced by BLE should be accepted as normal therefore depends on the definition of normality (Stones, Kozma, & Hanna, 1990). In sum, it is clear that the effect of physiological aging (i.e., calendar age) is not studied by merely examining different age groups after leaving out the diseased subjects. Ligthart (1989) stated that, with respect to the aging immune system, one measures the effects of diseases and other health-threatening factors rather than aging as such.

A second implication of controlling for BLE concerns the validity of other aging research. Whenever authors of experimental studies do not control for factors that are not intrinsic to calendar age (Stones et al., 1990), such as the health status of their subjects, it is unclear to which subset of the population their findings relate. Although our procedure of subject selection may not reflect the true distribution of health-related factors in the whole population, it is clear that using criteria that have hitherto received little attention can affect age trends in cognitive performance.

Finally, in selecting participants in the present study, we found that many individuals who judged themselves healthy had apparently forgotten that there were serious conditions impairing brain function in their medical histories and only recalled them after they were explicitly asked about them. Therefore, self-reported unidimensional health is not a reliable enough indicator of health and should be supplemented by a thorough survey and preferably by objective measurements. Findings such as those by Elias, Robbins, Schultz, and Pierce (1990) warrant this conclusion. It is questionable, however, whether subtle health factors such as the BLE investigated in the present study can be identified by means of objective measurements alone. Very careful medical history taking seems obligatory if one's aim is to exclude all age-extrinsic health factors that might possibly affect the optimal functioning of the brain.

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