Age-related decline of psychomotor speed

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AGE-RELATED DECLINE OF PSYCHOMOTOR SPEED: EFFECTS OF AGE, BRAIN HEALTH, SEX, AND EDUCATION [1]

PETER J. HOUX AND JELLEMER JOLLES

University of Limburg

Summary.—A cross-sectional study into age-related decline of psychomotor speed is reported. A newly introduced choice response task was used, involving three conditions: simple reaction time (SRT), choice reaction time (CRT), and CRT with stimulus-response incompatibility. Subjects were 247 volunteers, aged 20 to 80 yr. in seven age levels. Although all subjects thought themselves to be normal and healthy, a *post hoc* division could be made based on biological life events (BLE, mild biological or environmental factors that can hamper optimal brain functioning, such as repeated general anesthesia). Performance was poorer by subjects who had experienced one or more such event: slowing was comparable to the effect of age, especially in the more difficult task conditions. There were significant effects of sex and education, men being consistently faster than women, and more highly educated subjects performing better than subjects with only low or medium education. These findings replicate observations from other test methods. They are also in line with several other studies giving interactions between the effects of aging and physical fitness. This study questions the validity of much research on aging, as the data suggest that a more rigorous health screening for biological life events in subjects recruited from the normal, healthy population can reduce performance effects normally ascribed to aging.

Age-related decline of psychomotor speed is a very well-documented phenomenon (Welford, 1985; Salthouse, 1985; Jolles, 1986). Also, performance differences between age groups tend to increase as task complexity is raised (Simon & Pouraghabagher, 1978; Myerson, Hale, Hirschman, Hansen, & Christensen, 1989). Several authors have reported that a number of factors can interact with the effect of aging as such (Spirduso, 1975; Spirduso & Clifford, 1978). Among these factors are physical fitness (Milligan, Powell, Harley, & Furchtgott, 1984), brain damage (Hicks & Birren, 1970), education, and perceived health (Era, Jokela, & Heikkinen, 1986). Spirduso (1980) has reviewed the evidence on the relation between physical fitness and psychomotor speed. She found that fitness was directly related to reaction time and that with physical training both reaction and movement times could be shortened. Conversely, performance is slower in subjects with hypertension and other forms of cardiovascular disease. A major problem with relating psychomotor speed, and indeed any aspect of cognitive performance, to health and aging is the indirectness of the health measures. Self-perceived health is not always a good predictor of actual health or performance (Salthouse, Kausler, & Saults, 1990). Many health status factors (such as alcohol consumption or chronic medication) are not usually controlled for in studies on aging.

Houx, Vreeling, and Jolles (1991a, 1991b) have shown that some health-related factors were as adequate in predicting cognitive performance as aging *per se*. For instance, after controlling for these factors, no age-related decline was found in the maximum performance on a verbal memory test. Age effects on the speed of memory search or the amount of language interference experienced on the Stroop Color-Word Test were also greatly reduced after controlling for factors that are known to be associated with brain dysfunction. These findings were in line with data presented by Haxby, Grady, Duara, Robertson-Tchabo, Koziarz, Cutler, and Rapoport (1986) and by Perlmutter and Nyquist (1990).

During the last decade, several other authors have argued that age-related cognitive decline is not a monocausal, unitary concept. For instance, Rabbitt (1986) showed that the smooth decline of cognitive performance often reported in the vast literature of cross-sectional studies can be a mere consequence of the fact that the older age groups contain more poorly performing subjects. Arbuckle, Gold, and Andres (1986) found that age was much poorer in accounting for variance in memory performance than contextual variables such as education, intellectual activity, or personality scores. This was replicated by Craik, Byrd, and Swanson (1987). Perlmutter and Nyquist (1990) found that both self-reported physical and mental health accounted for a significant amount of the variance in intelligence performance, particularly among older adults.

The decline in cognitive functioning with increasing age may be continuous, but this continuum can be disrupted or accelerated in many individuals by what we term "Biological Life Events" (BLE). By definition, such events are mild biological or environmental factors that can hamper the optimal functioning of the brain (Houx, *et al.*, 1991b). We proposed recently that a thorough selection of subjects based on such events will greatly reduce the magnitude of the age-related decline in performance (Houx, *et al.*, 1991a). Thus, these biological events should be seen as an important source of interindividual variation, as are intelligence, education, and other factors mentioned by researchers in the field of aging; e.g., Salthouse, Kausler, and Saults (1988) mentioned occupational status or hours per week spent reading. Examples of biological life events are: exposure to organic solvents or other neurotoxic factors (Hartman, 1988), repeated very mild minor head injuries without direct cognitive sequelae (Binder, 1986), or systemic diseases like diabetes (Skenazy & Bigler, 1984).

To date, as is evident from several authoritative handbooks on aging (e.g., Birren & Schaie, 1985; Charness, 1985), little attention has been paid to the direct relationship between the biological life events that potentially result in brain dysfunction on the one hand and in cognitive dysfunctions that seem to be related to aging on the other.

Some authors have related reaction time to physical health or brain dysfunction. Letourneau (1990) assessed choice RT as a measure of recovery from general anesthesia. No conclusions could be drawn, as the test was not reliable. Offenbach, Chodzko-Zajko, and Ringel (1990) reported a negative relationship between fitness and speed of performance but no relation with general cognitive functioning. MacFlynn, Montgomery, Fenton, and Rutherford (1984) found that patients with minor head injury showed poorer performance at six weeks follow-up but not after six months. Milligan, *et al.* (1984) reported significant reaction time differences due to physical health and psychosocial variables.

It has been the aim of the present study to establish whether controlling for a number of biological life events could reduce the size of observed age-related decline of choice reaction time and movement speed. For this purpose, a new easy-to-administer test of psychomotor speed was developed. The test had to be applicable in clinical settings, so it was to be simple, regarding both instructions and task requirements.

Analogous to the method presented by Frowein and Sanders (1978), a test was constructed for which many task conditions could be manipulated. Most importantly, the amount of motor planning, prior to the actual movement execution, could be controlled. This was achieved by adjusting the number of alternative stimuli and introducing the element of stimulus-response incompatibility, meaning that stimulus and response do not coincide on the stimulus array. Neuropsychologically speaking, this has the advantage that the delay associated with the extra amount of motor planning can be studied. This is particularly of interest as slowing of motor planning and other aspects of behavioral organization might be indicative of frontal cortex involvement (Jolles, 1986). This, in turn, is of relevance as there are indications that loss of frontal neurons occurs as early as the fourth decade of life (Haug, 1985).

METHOD

Subjects

All subjects were recruited through advertisements in local newspapers or from a local brass band, sports club, or old people's home. Normal, healthy volunteers had explicitly been requested. Subjects were preselected over the telephone: only those applicants who regarded themselves as being healthy, normal, and not in need of any 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. 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 indicated major diseases or events with repercussions on the

brain. The subjects were then screened before the actual testing. Nine additional subjects did not pass this screening: six subjects were demented, as assessed by the Mini-Mental State Examination (Folstein, Folstein, & Mc-Hugh, 1975) with a score of less than 24, two subjects appeared to have had a major head injury resulting in persisting cognitive dysfunctions in their medical history (available to the examiners), and one 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. The average physical and mental condition of our subjects was at least as good as that of subjects in any experiment reported in the literature.

Care was taken to balance the level of education in each cohort and each subgroup. For this purpose, we used a Dutch scoring system developed by Verhage (1964) with 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 analyses in 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 the equivalent of $14.00 for their participation in the experiment.

Subject Assignment to Groups With and Without Biological Life Events

The 247 subjects were subjected to a semistructured and semiquantitative interview concerning biological life events prior to actual testing by a neurologist. Nine categories of events were identified, varying from minor neurological dysfunctions, repeated mild head trauma, or repeated general anesthesia, to complications at birth, such as perinatal hypoxia (see Houx, *et al.*, 1991b for a complete description). Each event was scored either present or absent. Subjects who had experienced one or more were assigned to one of seven groups, with mean ages ranging from 20 to 80 years. Subjects who had not experienced any biological life events were assigned to a corresponding 'healthy' age group. In each age group, about half of the subjects were men. It appeared that of 31 subjects aged 20, nine subjects had experienced one or more such events, and this ratio increased for every successive age group (see Table 1 for the exact numbers of subjects). As the number of applicants who had experienced these events by far exceeded the number of persons who had not in the elderly groups, not all of the elderly subjects with such experiences were investigated neuropsychologically. This was to avoid too great a change in the number of subjects in the healthy or biological life events groups per age.

Instrumentation and Procedure

For the choice response task, there were three subsequent conditions of

TABLE 1
Composition of Various Experimental Groups With and Without Biological Life Events: Age and Education

	20 yr.		30 yr.		40 yr.		50 yr.		60 yr.		70 yr.		80 yr.	
	Age	Education	Age	Education	Age	Education	Age	Education	Age	Education	Age	Education	Age	Education
Biological Life Events 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
Biological Life Events 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.—Age = in years (Verhage, 1964).

increasing task complexity. Briefly, a button was lit, in response to which this or another button was to be pressed. The conditions involved, in a fixed order, (1) simple reaction time, (2) choice reaction time adding a response selection phase to the simple RT condition, and (3) incompatible choice reaction time adding stimulus-response incompatibility to the choice RT condition.

Measurements were obtained from a six-button panel (see Fig. 1) containing one red button and five white target buttons, laid out in a 180° arc, all at 6 cm distance from the red button. The panel was connected to an Apple II microcomputer via an interface that was developed in our own laboratory. All buttons could be illuminated (stimulus onset) and button presses could be read out by the computer, both with 1-msec. precision. Basically, the subject was requested to hold down the red button with the index finger of the preferred hand as long as no white button was lit. As soon as this happened, the person was to release the red button and shortly press the lit button (or a button adjacent to it) with the same finger. After the target button had been pressed, the lit button went out and the red button was again to be held down until the next white button was lit. Subjects were explicitly instructed not to release the red button until they were quite sure which white button they were going to press. All instructions to the subjects were standardized. Two-millisecond time registrations per stimulus-response trial occurred: (1) initiation time (msec. needed to release the red button) and (2) movement time (msec. needed to move from the red button to the target button).

For the purposes of the present experiment, only the first two measurements were recorded as raw data. For simple RT, only the upper button was lit, and the subject was requested to press this button as quickly as possible. For choice RT, one of the three upper buttons was lit and to be pressed. Choice RT with incompatible stimulus-response was similar to choice RT; however, the button immediately adjacent (clockwise) to the lit button was to be pressed, instead of the lit button.

In the conditions of choice RT and choice RT with incompatible stimulus-response, the order of stimulus lights was semirandomly determined (no stimulus more than three times in succession), and the same for all subjects. The instructions were given orally by the experimenter. In many instances, especially for older subjects, the instruction had to be repeated and rehearsed in detail to make sure that the subjects had understood the whole procedure. There was a set of at least 15 practice trials per condition immediately preceding the actual test trials. If, during these practice trials, a subject waited 5 seconds or more to release the red button or pressed the wrong white button, the trial was repeated before proceeding to the test trials. The subjects were unaware of the transition from practice to test trials. For each condi-

tion, the mean, median, and standard deviation of initiation and movement times were calculated of 20 test trials. Only the medians per condition were analyzed for the present study, allowing an occasional extremely long initiation or movement time.

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 memory-scanning task was administered in addition to other tests. The results of these are discussed elsewhere (Houx, *et al.*, 1989, 1991a, 1991b). The whole procedure took about two hours.

Statistics

Analyses of variance were conducted with group age (7 levels), biological life events (2 levels), education (2 levels), and sex (2 levels) as between-subject effects. Student t tests were used to assess over-all group differences associated with sex, biological life events, or education. Spearman's rank-order correlations were performed to analyze relationships between aging, biological life events, and test scores. Alpha values smaller than 5% were taken to denote statistical significance.

<div align="center">RESULTS</div>

Tables 2 and 3 summarize the mean scores per test parameter in all age groups of subjects unaffected or affected by biological life events. In Fig. 1, mean reaction and movement times are plotted.

Different Task Conditions

Among the vast majority of the subjects choice RT was slower than simple RT (see Tables 2 and 3; over-all average: 16.2%), and choice RT with *incompatible stimulus and response was slower than choice* RT (41.5%). This was apparent from the effect of repeated measures ($F_{2,406} = 444.65$, $p < .001$). To initiate a motor response appears to take longer when there are alternative responses, and even longer when stimulus and response are incompatible. The same effect of condition was found for movement times ($F_{2,406} = 30.60$, $p < .001$), movements in every successive condition taking more time (6.9% and 10.9%, respectively). As also illustrated by Figs. 1a and 1b, both the preparation and the actual movement take significantly longer when response requirements become more difficult, especially when the response is stimulus-incompatible. Errors occurred only in the choice RT with the incompatible stimulus and response condition.

Age Effects and Interactions

Age-dependent decrements in speed can be observed from Figs. 1a and 1b. A significant age effect over all three conditions was found for the initiation time ($F_{6,216} = 25.53$) as well as movement time ($F_{6,216} = 16.03$, $p <$

TABLE 2
Means and Standard Deviations Per Test Parameter:
Biological Life Events Absent

Task/Parameter		Age Group (n)						
		20 yr. (22)	30 yr. (20)	40 yr. (22)	50 yr. (20)	60 yr. (20)	70 yr. (25)	80 yr. (21)
Simple Reaction Time								
Initiation	M	289.4	289.1	294.6	283.6	307.9	326.0	343.3
	SD	35.7	26.8	35.3	20.4	57.7	37.9	48.7
Movement	M	96.6	94.7	107.1	105.5	132.1	152.4	160.0
	SD	25.3	24.4	24.4	23.3	37.3	62.5	38.4
Choice Reaction Time								
Initiation	M	317.9	331.6	341.5	333.8	357.8	376.9	397.5
	SD	39.4	22.7	35.1	26.4	49.0	43.1	47.6
Movement	M	103.2	100.7	113.1	112.0	149.8	159.1	163.3
	SD	24.6	20.5	25.6	27.6	69.0	54.9	34.4
Choice Reaction Time, Incompatibility								
Initiation	M	405.9	418.8	437.9	426.4	483.6	512.2	538.4
	SD	52.8	48.7	67.7	48.1	102.1	80.4	81.0
Movement	M	105.8	101.4	115.0	123.0	159.1	187.0	190.2
	SD	29.2	29.7	29.5	41.9	90.0	82.2	38.3
Errors	M	0.2	0.1	0.3	0.1	0.3	0.0	0.3
	SD	0.4	0.3	0.7	0.2	0.4	0.2	0.5

.001). Age had no effect on the percentage of extra time needed for choice RT relative to simple RT (see Tables 2 and 3; $F < 1.00$), but the amount of delay due to stimulus-response incompatibility was significantly larger for older subjects ($F_{6,216} = 10.79$, $p < .001$). Also, there was interaction of age $\times$ repeated measurement in different conditions ($F_{12,432} = 18.99$, $p < .001$). The same effects were found for the movement time (age: $F_{6,216} = 16.03$, $p < .001$; age $\times$ condition interaction: $F_{12,432} = 5.34$, $p < .001$), indicating that motor initiation and execution both took longer for older adults, especially when response requirements were more difficult. Regarding movement times, there was no age effect on the difference between choice and simple RT ($F < 1.00$), but older subjects showed a significantly increased delay for choice RT with incompatible stimulus and response and choice RT. Older subjects made more errors ($F_{6,216} = 2.65$, $p < .05$), but the number of errors were usually few (mean number of errors 0.3 over $3 \times 20 = 60$ test trials, max. $= 6$; see also Tables 2 and 3).

Effects of Biological Life Events

Subjects in this group were slower in initiating movement ($F_{1,216} = 23.69$, $p < .001$) and carrying it out ($F_{1,216} = 5.08$, $p < .05$). Also, they made more errors ($F_{1,216} = 4.99$, $p < .05$). Biological life event-affected subjects were much slower than unaffected subjects in choice RT with and without incompatibility ($F_{2,432} = 30.40$, $p < .001$ for initiation; $F_{2,432} = 5.34$, $p < .001$ for move-

TABLE 3
Means and Standard Deviations Per Test Parameter:
Biological Life Events Present

Task/Parameter		Age Group (n)						
		20 yr. (9)	30 yr. (9)	40 yr. (12)	50 yr. (15)	60 yr. (15)	70 yr. (17)	80 yr. (20)
Simple Reaction Time								
Initiation	M	281.1	288.1	294.1	307.1	330.0	367.7	451.6
	SD	28.0	45.7	31.7	32.6	38.1	108.7	164.7
Movement	M	83.8	103.2	95.7	121.0	158.7	180.4	249.8
	SD	18.6	24.2	21.5	29.7	61.1	98.0	140.4
Choice Reaction Time								
Initiation	M	329.6	320.3	325.9	341.3	397.7	435.2	515.8
	SD	37.0	48.0	29.3	37.7	45.0	140.9	173.8
Movement	M	91.8	105.4	101.6	129.5	161.3	176.4	270.9
	SD	23.3	26.2	17.5	27.4	52.3	85.4	179.5
Choice Reaction Time, Incompatibility								
Initiation	M	405.9	435.8	434.3	464.2	543.4	803.8	1023.8
	SD	38.3	68.7	35.0	66.0	71.3	332.6	356.3
Movement	M	93.6	108.0	104.8	132.9	182.3	251.2	348.1
	SD	25.6	29.3	21.3	26.9	70.1	213.4	228.7
Errors	M	0.1	0.1	0.3	0.1	0.5	1.0	1.4
	SD	0.3	0.3	0.6	0.2	1.1	2.1	1.7

ment). There was a significant interaction of age × biological life events regarding over-all speed in all three conditions ($F_{6,216} = 7.99$, $p < .001$ for initiation only) and an interaction of age × biological life events × condition ($F_{12,432} = 10.53$, $p < .001$ for initiation only). All biological life events × age groups were slower in initiating movement, and the difference with biological life event-unaffected subjects widened with increasing age. Biological life event-affected subjects made more errors (mean number of errors was 0.6 vs 0.2 in the event-free group; $F_{1,216} = 4.99$, $p < .05$). There was no age-related decline of accuracy in biological life event-unaffected subjects.

Sex Differences

Women tended to be slower than men: the over-all average slowing in women's initiation time relative to the men's was 6.9% ($F_{1,216} = 5.40$, $p < .05$), and for movement time women were even 33.9% slower than men. There was no interaction with age ($F < 1.00$ for both initiation and movement times), indicating that the sex difference was independent of age. There was, however, interaction with biological life events ($F_{1,216} = 7.69$, $p < .01$ for initiation and $F_{1,216} = 5.78$, $p < .05$ for movement), the sex differences being larger for the biological life event-affected subjects. Biological life event-unaffected women were even somewhat faster in initiating movements (3.1%), but slower in the execution (12.5%). Biological life event-affected women, however, needed 19.5% more time to initiate and 61.6% more time

to execute a movement. It appears that motor performance of women is impaired more from biological life events than for men. No differences in accuracy due to sex were observed.

Education

Education had no significant effect on initiation times (better-educated subjects were 13.4% faster; $F_{1,216} = 2.88$, ns), but rather surprisingly, it did affect the movement times as better-educated subjects were 26.2% faster ($F_{1,216} = 4.66$, $p < .05$). None of the interaction terms with education were significant. Thus, irrespective of age, biological life events, or sex subjects who had more schooling moved substantially faster, but education did not affect the number of errors.
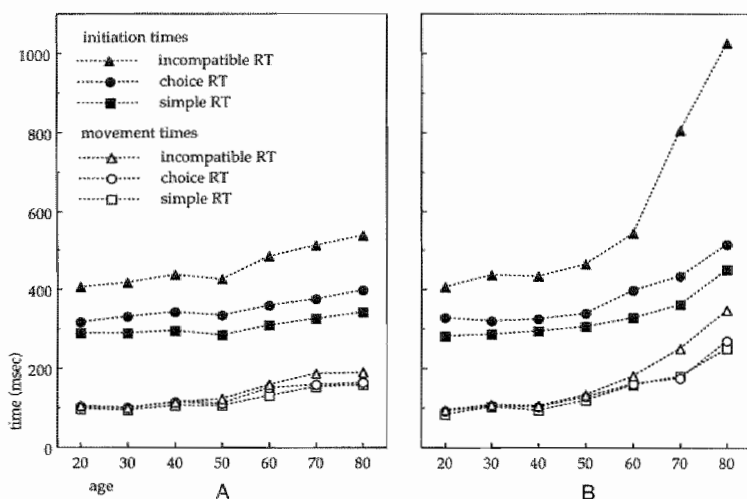

Fig. 1. Mean reaction and movement times in three conditions of the choice response task, for subjects either without (A) or with (B) Biological Life Events (Houx, *et al.*, 1991b)

Influence of Separate Biological Life Events

The present study was not planned to investigate prospectively the effects of individual biological life events on motor performance. As a consequence, the prevalence of biological life events can differ widely over the various age groups. However, correlations between test performance with age, education, and biological life events can be compared. Spearman's rank-order correlations between several measures of performance and age were usually about 0.60. Table 4 gives correlations between test performance and age, education, number of experienced biological life events, and those events that yielded at least one significant correlation.

Although these values are statistically significant, both age and educa-

TABLE 4
SPEARMAN'S RANK-ORDER CORRELATIONS OF TEST SCORES WITH AGE, EDUCATION, NUMBER OF EXPERIENCED BIOLOGICAL LIFE EVENTS, AND TWO SEPARATE BIOLOGICAL LIFE EVENTS

Task / Parameter	Age	Education	BLE, no.	General Anesthesia	Medications
Simple Reaction Time					
Initiation	.501†	−.277*	.190*	.221*	.349*
Movement	.628†	−.330†	.159†	.243†	.365†
Choice Reaction Time					
Initiation	.613†	−.272†	.171†	.183†	.376†
Movement	.625†	−.374†	.138*	.263†	.340†
Choice Reaction Time, Incompatibility					
Initiation	.664†	−.215†	.283†	.261†	.418†
Movement	.676†	−.350†	.134†	.191†	.389†

Note.—Number of biological life events given in Table 1 as experienced by a subject; for general anesthesia score was weighted; number of different medications taken regularly.
*$p < .05$. †$p < .01$: t-test, two-tailed.

tion leave considerable variation unaccounted for. The number of biological life events these subjects had experienced during their lives appeared to correlate even more weakly. Correlations between performance and other biological life events than given in Table 4 seldom exceeded .10 and did not reach significance. It can be said, therefore, that age and education are better predictors of test performance than biological life events, although these can certainly not be ruled out.

DISCUSSION

Over-all age-related slowing was found for all conditions of a new choice reaction test. This slowing was greatest in motor execution times, whereas slowing in initiation was mainly present in the condition involving stimulus-response incompatibility. Apart from age, furthermore, sex, education, and most importantly biological life events accounted for a substantial and significant amount of interindividual variance. The finding of slowing of motor-preparation processes that is more marked in difficult task conditions is in line with the notion of Spirduso (1980), Welford (1977, 1985), and many others, that motor initiation is a central process and as such vulnerable to the effects of aging.

Much less in line with Welford's reasoning, however, is the finding that the motor-execution stage in the choice reaction test presently discussed actually shows more age-related slowing than the preparation stage. The average initiation times of subjects aged 70 to 80 compared to those of subjects aged 20 to 30 were 28% slower in the simple RT condition, 32% slower in the choice RT condition, and 70% slower in the choice RT condition with incompatible stimulus and response (see the Method section for description). By contrast the corresponding percentages for the movement times were 93%, 89%, and 134%, respectively. Close inspection of the data

of Spirduso and Clifford (1978) indicates that movement times of old men are also more slowed down than reaction times, although the age differences were less marked than those found in the present study. A study by Era, *et al.* (1986) shows roughly the same pattern: age-related slowing in movement times was at least as large as the slowing in reaction times, depending on the task conditions. The most likely explanation seems that part of the response preparation takes place during the actual movement from the button-to-be-held-down to the target button. This would also explain why the movement time is also affected by the condition, a finding that is also inconsistent with the notion of Frowein and Sanders (1978) that the initiation time reflects all of the response preparation, as expressed by Fitts (1954). Although the subjects were instructed not to respond until they were sure about which button they were going to press, many subjects seemed to hesitate during both preparation and movement. This indecisiveness was particularly apparent in older subjects, especially women. This, in turn, is in line with Botwinick's (1977) notion that elderly subjects tend to be more cautious and therefore take longer to respond.

Another explanation for the greater proportion of delay in movement time might be that movements of untrained elderly subjects are generally much slower than young, often trained subjects. Era, *et al.* (1986) found significant slowing of tapping and knee-extension speed in a population study. Spirduso and Clifford (1978) replicated Spirduso's (1975) finding that reaction and movement times were directly related to the level of physical activity in which their subjects engaged. Old racquetball players were only 7% slower in reacting and 5% slower in moving than young racquetball players. Taking the absence of biological life events as a rough indication of physical health, correcting for biological life events markedly reduces the age-related slowing of reaction times to 15%, 19%, and 27% and of movements to 63%, 58%, and 81% for the three successive conditions. Subjects for the present study were not selected for physical training. It is supposed that rigorously selecting subjects based on physical activity would further reduce the age differences. An extensive study to test this hypothesis is currently being prepared.

Landauer (1981) reported that women were faster in decision times, but slower in movement times. Interaction with age was not evaluated. Lahtela, Niemi, and Kuusela (1985) found men to be faster across all age levels, but no interaction of sex × age. Sex differences seem to be rarely observed in relation with age in reaction time studies. Spirduso and Clifford (1978) and Era, *et al.* (1986) only investigated performance in men. In a study involving factor analysis, Vrtunski, Patterson, and Hill (1984) did not mention sex as an important subject variable. We found that men were generally faster in re-action and movement times in all task conditions. This was only apparent in

the older age groups, although the interaction of age × sex was not significant. There was, however, substantial interaction of biological life events × sex, both in reaction times and in movement times. In the choice RT with incompatibility condition, biological life event-unaffected women reacted 4% faster but moved 17% slower than men, consistent with Landauer's findings. In the biological life event-affected group, however, women reacted 26% and moved 86% more slowly than men. Further research will be aimed at the nature of this interaction of biological life events × sex.

Subjects who had received more schooling consistently were faster in reaction and movement times. At the simple RT, choice RT, and choice RT with incompatibility conditions, respectively, they reacted 11%, 9%, and 16% faster and moved 22%, 24%, and 30% faster. As there were no interactions, it is concluded that this effect of education is independent of age, sex, or biological life events. In the study by Era, et al. (1986), education was one of the most important covariates, the highest correlation being −.328, with movement in a visual choice RT condition. In our study, the highest correlation was −.396 (also movement time in the choice RT condition). There seems to be no intrinsic reason why education should be related to speed of movement. It might be that better educated people adopt a 'life style' enabling them to be more physically fit. Another possibility is that better educated subjects are better motivated to perform well in an experimental setting instead of needing monetary incentives.

As stated above, biological life events accounted for a substantial amount of the interindividual variation. Evidence was found for the hypothesis that biological life events play a significant role in age-associated performance decline, comparable to that of physiological aging as such. A broad range of adults was tested. After correction for biological life events, the observed age effect was much smaller than in the whole sample. Conversely, the groups of subjects affected by biological life events showed a much more pronounced age decline. This was especially the case in the task condition that involved stimulus-response incompatibility. Significant interactions were found between the effects of age and biological life events.

Rigorous screening for biological life events appears to reduce greatly the observed age effects. These findings are incompatible with a study by Salthouse, et al. (1990), who reported no reduction of age trends in cognitive functioning after correction for self-perceived health. As their measures of health status were rather crude, they deemed it premature to conclude that the relations between age and cognition are 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, or occupational status (Salthouse, et al., 1988). Our findings are very much in line, however, with Perlmutter and Nyquist

(1990) who state that 'the patterns of correlational analyses suggested that health probably accounts for a greater proportion of individual differences in older than in younger adults' intelligence performance.' Also, specific health-related variables have been studied for their relation to cognition. Elias, Robbins, Schultz, and Pierce (1990) found interactions of blood pressure with age for some neuropsychological parameters. Finally, the present outcomes are consistent with some of our earlier studies on other neuropsychological test performance, such as free recall and recognition of verbal material (Houx, et al., 1989) or speed of memory scanning (1991b).

It is clear from this study (and from other studies by ourselves and others) that controlling for biological life events in the assignment of subjects to experimental groups has far-reaching consequences for the outcomes of research on aging. In the first place, age effects are much smaller in subjects without biological life events than in an unselected sample. That implies that the average aging subject is not necessarily the most successfully aging subject. During the life span, the likelihood of experiencing one or more biological life events increases with age. It depends on the definition of normality, therefore, whether cognitive aging enhanced by biological life events should be accepted as normal. It is clear, however, that the effect of physiological aging, that is, calendar age, is not studied by merely examining different age groups. In doing so, Ligthart (1989) states 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 biological life events concerns the reliability of other aging research. Whenever authors of experimental studies do not mention some health screening of their subjects, it is unclear to which subset of the population their findings relate. We do not claim that our procedure of subject selection reflects the true distributions of health-related factors in the whole population. The essence is, however, that based on criteria that have hitherto received very little attention, very different age trends can be observed. This is in accordance with Rabbitt's (1986) notion of 'individual age-performance trajectories,' i.e., individuals can age cognitively along different routes. Some show a gradual decline, others' performance can drop suddenly, and some keep their performance intact until very late in life, at least regarding many aspects of cognitive functioning (Houx, et al., 1991a). The resulting mean is a gradual decline with age, but this does not necessarily reflect the actual aging pattern of most, let alone all, individuals.

Presently, a five-year follow-up of the current study is being planned, using the same sample of subjects. Furthermore, a larger prospective study is being prepared in which the relative effects of each individual biological life event will be studied. It might very well be that the differential age trends

observed in this study will not *exactly* be replicated in a sample of aging subjects which mirrors the actual epidemiological proportion. What remains, however, is that two very differently performing groups can be drawn from the same normal and healthy population by establishing whether or not subjects have experienced biological life events.

The test used in the present experiment appeared to be easy to administer and very sensitive to a number of subject variables. Moreover, the instructions are generally well understood, even by patients. It has already proven its value in clinical settings (Brand, Van Wijk, & Hijman, 1990). Curran, Wattis, and Hindmarch (1989) and Mahurin and Pirozzolo (1986) have used a similar test (without the S-R element of incompatibility, however) with dementing patients. Thus, choice reaction tests seem to constitute a useful paradigm in assessing dysfunctions in neuropsychological patients and in studying age-related decline of planning and execution of motor reactions.

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