Decline of psychomotor performance

DECLINE OF PSYCHOMOTOR PERFORMANCE: CALENDER OR HEALTH?

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ABSTRACT. A cross-sectional study into age-related decline of psychomotor speed is reported. A newly introduced tapping test was used, enabling the analysis of ongoing performance. Although all subjects thought themselves to be normal and healthy, a post-hoc division could be made based on biological life events (BLE). BLE are mild biological or environmental factors that can hamper optimal brain functioning, such as repeated general anesthesia. Performance was poorer in subjects who had experienced one or more BLE. Their tapping started at a lower level, and they slowed down faster. These findings replicate observations from other test methods. 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 much aging research hitherto performed, as the data suggest that a more rigorous health screening for BLE in subjects recruited from the normal, healthy population can reduce much of the performance effects, normally ascribed to aging as such.

1. Introduction

During 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 poorly performing subjects due to 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 both accounted for a significant proportion of the variation in intelligence performance, particularly in older adults. Elias et al. (1990) thoroughly discuss methodological issues in the study of interactions between health and age regarding behavioral changes, and cite data on various diseases such as cardiovascular disease, diabetes, or Parkinson's disease. They rightly state that the amount of information on age x health interactions have 'exploded' in the last few years. However, in our view, too little attention has been paid to what Rowe and Kahn (1987) term 'usual', non-diseased aging, as it is affected by 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, 1991). 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 et al., 1991). Thus, BLE should be seen as an important source of inter-individual variation, as are intelligence, educational level and other factors mentioned by researchers in the field of aging (e.g.,

G.E. Stelmach and V. Hömberg (eds.), Sensorimotor Impairment in the Elderly, 31–39.

Salthouse et al. (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 very mild minor head injuries without direct cognitive sequelae (Binder, 1986). Houx et al. (1991) found an enhanced age-related decline 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. These authors observed a much smaller age effect on visual memory than is usually reported in elderly men who had passed a 'rigorous health screening'.

The present study investigated the possible interactions of aging and BLE in their effect psychomotor speed, as measured with a modified tapping test. Finger tapping speed is one of the more simple aspects of psychomotor performance and manual dexterity that are known to deteriorate with advancing age (Bak and Greene, 1980; Harley et al., 1980; Welford, 1985). To test tapping speed in neuropsychological patients, Halstead (1947) devised a test that was originally named the *Finger Oscillation Test*, but is now better known as *Finger Tapping Test* (FTT), as part of the Halstead-Reitan Neuropsychological Test Battery (See Lezak, 1983, pp. 529 and 562-566, for a concise discussion). The FTT is now the most widely used test of simple manual motor speed. Also, it is often used to test performance differences between both hands in order to evaluate lateralized brain lesions, which often result in slowing of the tapping rate of the contralateral hand (Finlayson and Reitan, 1980; Haaland and Delaney, 1981).

Briefly, the test consists of a tapping key, attached to a tap-counting device, mounted on a small piece of board. Each hand makes five 10-seconds trials, with brief rest periods between the trials, by alternating the hands. The score for each hand is the average of all five trials. Dodrill (1979) described a group of 47 men and 47 women, the men averaging at almost 56 taps in ten seconds, the women 51 taps. This sex difference was significant. As yet, no age norms founded on sufficiently large groups of normal healthy controls are available.

Although the FTT is a handy, easy-to-administer test, is has some limitations. The tapping key is mounted to the counting-device in such a way, that many subjects experience trouble in speed finger oscillation. The wrist has to be placed on the board on which it is mounted, whereas the key is situated some 4 cm. higher. This is quite uncomfortable, so that low tapping rate may be due to this technical problem, especially in patients or subjects with small hands. More importantly however, the counting device merely registers the number of taps, not their timing. It was our clinical impression though, that the tapping rate slowed down during each ten-seconds trial. It has been our aim therfore, to devise a simple, clinically applicable test of manual motor proficiency, that would take into account the development of the performance over time.

For purposes of motor reaction timing (Brand, 1987) a console was available, in which easy-to-press down keys were mounted, which could in turn be read out by an Apple-II microcomputer. This enabled the construction of a new test. To the well-recognized advantages of computerizing cognitive and neuropsychological tests, two can be added regarding the newly developed tapping test: 1. the period during which the subject is tapping can be much more accurately timed than by means of a stopwatch (at millisecond precision), and 2. the tapping period can be divided into successive blocks, in order to determine in which interval performance is at it's best, whether there is any decline in tapping speed, and, if so, at what rate this decline occurs. Regarding attention and reaction time, this procedure was described earlier by Gaillard and Varey (1979).

1.1 TEST DESCRIPTION

The technical aspects of the hardware of the test are dicussed by Houx (1991), and in greater detail by Brand (1987). The procedure of the tapping test used in the present study, the *Continuous Performance Tapping Test (CPTT)* differed from the FTT. There were three 20-second trials for each hand. The time elapsed between two single taps was registered by the computer, at millisecond accuracy. For the purposes of this experiment, the 20-second trials were subdivided in four five-second intervals. The tapping rate during these blocks served as raw data for further analysis.

Analogous to the FTT, the average of the three corresponding intervals for the four trials were calculated, to yield four interval scores for each hand. These scores served as data for a linear regression analysis for every individual subject. Thus, apart from an over-all mean score, an intercept, slope, and linearity coefficient was calculated for each hand. Finally, the difference between the over-all mean scores of the preferred hand minus the non-preferred hand was expressed in a personal delta-score.

2 Method

2.1 SUBJECTS

Subjects (normal, community-dwelling volunteers) were recruited by means of advertisements in local newspapers or from a local brass band, sports club, or old people's home. Normal, healthy volunteers had explicitly been asked to reflect. Subjects were pre-selected 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 and 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 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 (MMSE; Folstein, Folstein, and McHugh, 1975), with a score of less than 24, two subjects appeared to have had a major head injury resulting in persistent cognitive dysfunctions in their medical history (available to the examiners), and one subject had been treated for 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.

2.1.1. *Subject Assignment To Groups With And Without BLE.* The 247 subjects were subjected to a semi-structured and semi-quantitative interview concerning BLE prior to actual testing. Nine categories of BLE 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. (1991), for a complete description). Each BLE was scored either present or absent. Subjects who had experienced one or more BLE were assigned to a separate 'BLE' x age group. Subjects who had not experienced any of the BLE were assigned to a corresponding 'healthy' age group. There were 2 x 7 discontinuous age groups with mean ages ranging from 20 to 80 years. Irrespective of BLE the goup ages were 20.1±1.8, 30.4±1.7, 39.9±2.0, 49.8±1.8, 59.8±2.1, 69.7±2.1, and 79.1±2.0. In each age group, about half of the subjects were male.

It appeared that of 31 subjects aged 20 years, nine subjects had experienced one or more BLE, and this ratio increased for every successive age group (see table 1 for the exact numbers of subjects). As the number of applicants in the elderly age groups who reported to have experienced BLE by far exceeded the number of persons who did not, not all of the elderly BLE subjects participated in the actual testing. This was 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 cohort and each subgroup. For this purpose, we used a Dutch scoring system adapted from 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 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.

Table 1. Composition of the experimental groups with / without BLE: age and education

	±20 years age	educ	±30 years age	educ	±40 years age	educ	±50 years age	educ	±60 years age	educ	±70 years age	educ	±80 years age	educ
	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: age = in years; educ = education level (Verhage, 1964).

3. Results

Figure 1 depicts the average interval performance of subjects with and without BLE. Table 2 summarizes the individual linear regression parameters. An ANOVA was carried out which had age (7 levels), BLE (2 levels), education (2 levels), and sex as main between subjects effects, and interval (4 levels) and hand as within subjects effects. Furthermore, three ANOVA's for individual parameters were performed: over-all mean, intercept, slope, and linearity coefficients, each of these with the same between subjects effects as the one mentioned above, and hand as within subjects effect.

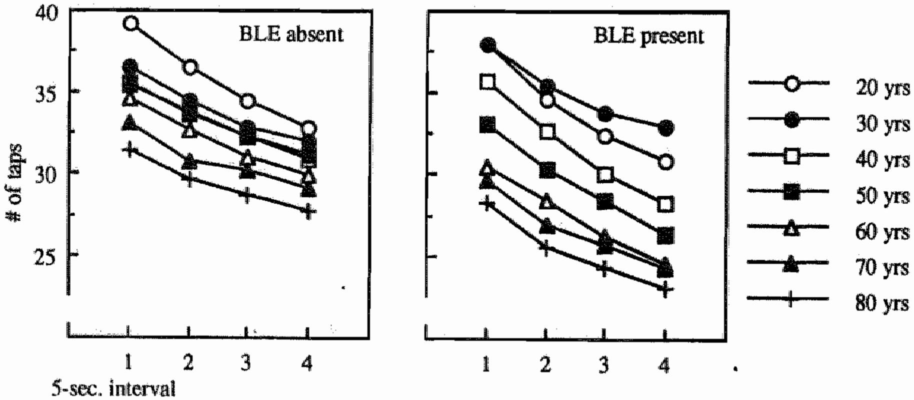

Figure 1. Mean number of taps of 3 successive 20-sec. trials with the preferred hand, divided in 5-sec. intervals. The graph on the right summarizes the performance of otherwise normal and healthy subjects who had experienced biological life events (BLE).

Table 2. Norm values: mean scores (and standard deviations) per test parameter

	Age group						
	20	30	40	50	60	70	80
Biological life events absent							
# of subjects	22	20	22	20	20	25	21
NON-preferred hand							
Mean score	32.1 (4.6)	30.6 (3.1)	30.8 (3.4)	30.5 (3.2)	29.0 (3.1)	27.8 (3.6)	25.9 (2.7)
Intercept	38.0 (6.1)	36.0 (4.2)	35.2 (3.4)	35.0 (4.5)	32.9 (4.0)	31.6 (4.7)	29.5 (3.3)
Slope	-2.36 (1.45)	-2.13 (1.03)	-1.79 (0.96)	-1.79 (0.89)	-1.54 (0.80)	-1.50 (0.72)	-1.44 (0.64)
Linearity	-0.90 (0.14)	-0.92 (0.14)	-0.95 (0.08)	-0.91 (0.12)	-0.89 (0.25)	-0.90 (0.08)	-0.90 (0.12)
Preferred hand							
Mean score	35.7 (4.4)	33.9 (3.5)	33.0 (3.5)	33.2 (3.1)	32.0 (2.2)	30.8 (3.6)	29.4 (3.0)
Intercept	41.0 (5.2)	37.8 (3.2)	36.8 (3.4)	36.7 (4.3)	35.8 (2.6)	33.9 (3.4)	32.3 (3.6)
Slope	-2.13 (1.13)	-1.53 (0.72)	-1.51 (0.60)	-1.42 (0.85)	-1.53 (0.54)	-1.26 (0.74)	-1.18 (0.62)
Linearity	-0.89 (0.18)	-0.89 (0.17)	-0.92 (0.17)	-0.81 (0.41)	-0.96 (0.04)	-0.80 (0.21)	-0.85 (0.17)
DELTA	-3.59 (3.90)	-3.27 (2.11)	-2.29 (2.57)	-2.68 (2.00)	-2.97 (1.84)	-2.95 (2.13)	-3.50 (2.02)
Biological life events present							
# of subjects	9	9	12	15	15	17	20
NON-preferred hand							
Mean score	32.9 (4.1)	33.0 (3.0)	29.8 (2.7)	27.9 (4.0)	25.2 (3.9)	24.9 (4.7)	23.4 (4.4)
Intercept	38.4 (3.1)	39.0 (4.4)	35.5 (2.5)	33.8 (5.3)	29.9 (6.0)	29.3 (5.3)	26.6 (5.9)
Slope	-2.20 (0.92)	-2.40 (0.99)	-2.28 (0.96)	-2.35 (1.00)	-1.88 (1.10)	-1.74 (0.84)	-1.28 (0.91)
Linearity	-0.98 (0.01)	-0.91 (0.07)	-0.93 (0.17)	-0.97 (0.05)	-0.82 (0.34)	-0.90 (0.11)	-0.78 (0.34)
Preferred hand							
Mean score	34.0 (5.8)	35.0 (3.2)	31.6 (3.0)	29.6 (3.7)	27.5 (4.1)	26.7 (4.2)	25.3 (5.2)
Intercept	39.8 (6.6)	39.2 (3.3)	37.8 (3.4)	35.0 (5.2)	32.4 (4.6)	31.0 (4.4)	29.6 (5.4)
Slope	-2.34 (1.02)	-1.66 (0.60)	-2.46 (1.25)	-2.17 (1.13)	-1.98 (1.02)	-1.75 (0.71)	-1.68 (0.63)
Linearity	-0.93 (0.05)	-0.91 (0.10)	-0.97 (0.02)	-0.97 (0.03)	-0.93 (0.15)	-0.93 (0.05)	-0.91 (0.10)
DELTA	-1.04 (3.63)	-2.07 (2.45)	-1.83 (2.74)	-1.67 (1.48)	-2.29 (3.30)	-1.75 (2.36)	-1.99 (2.64)

Note: Mean score: average number of taps in 5 sec., in 3 successive trials, each involving four 5-sec. intervals. Interval, slope, and linearity: regression parameters of number of taps as a function of interval number, based on mean number of taps in all corresponding intervals of the 3 successive trials. Delta: difference between overall interval scores of preferred hand and non-preferred hand.

Effects of interval, hand, and sex. With each successive interval, the number of taps declined ($F(1,217)=183.88$, $p<.001$). The non-preferred hand was slower than the preferred hand ($F(3,651)=925.36$, $p<.001$), and slowed down faster ($F(1,217)= 5.34$, $p<.05$; slopes). Women were slower than men ($F(1,217)=30.95$, $p<.001$; intercepts); ($F(1,217)=1,217=36.24$, $p<.001$; over-all means). There were no other sex effects or interactions with sex.

Age effects and interactions. Interval tapping rates declined with advancing age ($F(6,217)=21.93$, $p<.001$). Age and interval showed interaction ($F(18,651)=3.53$, $p<.001$): tapping rate declined less over the successive intervals in older subjects. This was replicated by an age effect regarding the individual slope ($F(6,217)=4.42$, $p<.001$. Older subjects showed no greater difference between both hands than younger subjects ($F<1$). Over-all means and intercepts were also lower in older subjects: ($F(6,217)=21.93$, $p<.001$), and ($F(6,217)=24.36$, $p<.001$), respectively. Sex differences were no greater in older subjects ($F<1$).

Biological life events were associated with most aspects of performance. BLE-affected subjects had lower over-all means ($F(1,217)=17.14$, $p<.001$), steeper slopes ($F(1,217)=14.64$, $p<.001$), and larger hand differences ($F(1,217)=12.92$, $p<.001$), but they did not show significantly lower intercepts ($F(1,217)=2.77$, $p=.098$). Older subjects who had experienced BLE performed most poorly, as appeared from age x BLE interactions regarding over-all means ($F(6,217)=2.48$), $p<.05$). There were no other interactions.

Education showed two surprising effects of: higher educated subjects started off faster ($F(1,217)=5.7$, $p<.05$; intercepts), but also slowed down faster ($F(1,217)=4.35$, $p<.05$; slopes), which resulted in over-all means that showed no significant differences.

Linearity of performance decline over time. As can be seen from table 2, the average linearity of the decline over the successive intervals was quite high. In some age groups, means were negatively flattered because of high variance. Inspection of the raw data showed that this was mainly due to an occasional temporary lapse of the tapping which was otherwise quite high. Occasionally, a subject missed the tapping button.

The influence of separate BLE. As the study was not a prospective one, as to the impact of different BLE, only some separate correlations are given here with those factors that appeared to correlate significantly with test performance. Table 3 summarizes some of the relevant findings. Correlations that are not presented in the table were not significant. Of all the subject variables, age was most strongly related to tapping rate, but it was only weakly related to slope: older subjects tended to slow down less rapidly (or to start slower). Education was second best in explaining for the individual differences: there were moderate correlations with general speed. The number of BLE subjects had experienced was also related to all aspects of test performance: the higher the number of BLE, the steeper the slope. Of the separate BLE, only the number of different types of medication the subjects was taking regularly or had taken shortly before, could account for a substantial amount of variance. The number of closed head injuries was not related to any aspect of tapping performance; the number of anesthesias correlated only with the over-all mean.

Table 3. Correlations of tapping rate (preferred hand) with age and BLE

	Age	Educ	#BLE	#CHI	#anest	#medic
Mean	-.569**	.379**	-.290**	-.029	-.173**	-.389**
Intercept	-.605**	.375**	-.173**	.012	-.139*	-.379**
Slope	.198**	-.062	-.239**	-.095	-.051	.050

Note: Educ: education, scored according to Verhagen (1964); #BLE: number of BLE experienced by a subject; #CHI: weighed score of the number of closed head injuries; #anest: weighed score of general anesthesia; #medic: number of different medications, taken regularly. * $p<.05$, ** $p<.01$, t-test, two-tailed.

4. Discussion

With a newly constructed tapping test, several aspects of manual motor performance could be studied. There were age differences as to the over-all number of taps, but also in the course of the performance. Younger subjects were faster 'starters' but also slowed down more rapidly. Healthy elderly subjects apparently performed at a more constant level. Elderly subjects who had experienced BLE however, showed a faster decline. Furthermore, differences between young and old were larger in the BLE-affected group, irrespective of other factors. Subjects who had received more formal education performed somewhat better, but only in the first 5-second interval. In the other three intervals there was no significant difference. Of the separate BLE, the number of different medications taken regularly, correlated most strongly with test performance.

The finding of sex differences favoring men, supports Dodrill's (1979) findings. The size of the difference was roughly the same as found by Dodrill: nearly 3.0 in a five-second over-all means (Dodrill found women to be almost 5.0 taps slower in 10 seconds).

The absolute average tapping rate in the present study appeared to be somewhat (and in younger groups considerably) higher than in studies reported by Lezak (1983). She reports a maximum (in 10 seconds) of 55.9 for the preferred hand, and 51.1 for the other. The explanation is probably the better tapping device used in the present study.

The surprising differences due to education are difficult to account for. The size of the average difference between high- and low educated subjects regarding the intercepts was not very large: ±2 in the preferred hand, and ±2,7 in the non-preferred hand. Possibly the high-educated subjects were somewhat more motivated to do their best. Perhaps, the tapping test may bear some sportive challenge, to which some people are attracted.

The non-preferred hand was almost invariable slower than the preferred hand. Not only was it a slower starter (more than two point less), but also it appeared to fatigue somewhat faster (about 1.9 taps less every next interval, as opposed to 1.7 points in the right hand. See table 2 for the distribution over the age groups.

The complex interactions between age, BLE and performance in successive intervals is not quite unequivocal. Young subjects were fast starters, irrespective of BLE, but slowed down quickly in the following intervals. Apparently, they can summon enough energy to make a quick, explosive start. Older subjects did not slow down that quickly, irrespective of BLE. Possibly they have learned to better distribute their energy.

The data suggest that it is worthwhile to further develop this method. The CPTT has proven to yield extra information that cannot be drawn from the original Halstead test. Given a microcomputer in the examination room, administration is as simple and quick as with the old version. For purposes of the present study, the raw data were not analyzed to search for small temporary lapses of the tapping rate. This is, however, still possible. It was our experience that especially older subjects show more of these lapses, as if they 'lose the rhythm'. To study this, however, it is probably required to use longer test trials, for instance 60 seconds, instead of 20. The CPTT would then be transformed into a 'sustained tapping test'.

It is clear from this study (and from other studies by ourselves and others) that controlling for biological life events (BLE) in the assignment of subjects to experimental groups has far-reaching consequences for the outcome 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 and Kahn, 1987, for a very thorough discussion). Furthermore, the likelihood of experiencing one or more BLE increases with age. It therefore depends on the definition of normality as to whether cognitive aging enhanced by BLE should be accepted as normal (Stones et al., 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. With respect to the aging immune system, Ligthart (1989) states that 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 calender 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, many individuals in the present study judging themselves healthy, had apparently forgotten about serious conditions impairing brain function, that they only recalled when explicitly asked about. Therefore, self-reported unidimensional health is not enough (Perlmutter and Nyquist, 1990), and should be supplemented by a thorough survey and preferrably by objective measurements.

4.1 LONGITUDINAL RESEARCH

At present, a five-years follow-up of the cross-sectional study reported here is being performed, with all subjects and the same set of cognitive tests, of which the tapping test presented here is only one (Houx, 1991). Moreover, a very large cross-sequential study into cognitive aging is carried out. With this longitudinal project (Jolles, 1991), it is our aim to study in a prospective manner several BLE and other possible determinants of (less than) succesful aging. Among the other factors that may be of importance in determining cognitive performance in old age are psychosocial factors and 'life style'. Over 3,000 normal subjects with ages ranging from 25 to 85 will be examined cross-sectionally and followed over a period of at least 12 years. The programme also incorporates, a number of linked studies, involving patients with different type of neuropsychiatric and other conditions. Predictors of pathological aging and dementia are very important in this respect.

5. References

Arbuckle, T. Y., Gold, D., & Andres, D. (1986) 'Cognitive functioning of older people in relation to social and personality variables', Psychology and Aging 1, 55-62.

Binder, L. M. (1986) 'Persisting symptoms after mild head injury: A review of the postconcussive syndrome', Journal of Clinical and Experimental Neuropsychology 8, 323-346.

Botwinick, J. (1977). 'Intellectual abilities', in J. E. Birren & K. W. Schaie (eds.), Handbook of the Psychology of Aging, Van Nostrand Reinhold, New York, pp. 580-605.

Charness, N. (ed.). (1985) Aging and human performance. Chichester, UK: Wiley.

Craik, F. I. M., Byrd, M., & Swanson, J. M. (1987) 'Patterns of memory loss in three elderly samples', Psychology and Aging, 2, 87-86.

Dodrill, C. A. (1979) 'Sex differences on the Halstead-Reitan Neuropsychological Battery and on other neuropsychological measures', Journal of Clinical Psychology, 35, 236-241.

Elias, M., Elias, J., & Elias, P. (1990), 'Biological and health influences on behavior', in J. Birren, & K. Schaie (Eds.), Handbook of the Psychology of Aging (3rd ed.), Academic Press, San Diego, pp. 97-102.

Finlayson, M. A. J., & Reitan, R. M. (1980), 'Effect of lateralized lesions on ipsilateral and contralateral motor functioning', Journal of Clinical Neuropsychology, 39, 33-36.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975), "Mini-Mental State", Journal of Psychiatric Research, 12, 189-198.

Gaillard, A. W. K., & Varey, C. A. (1979) 'Some effects of an ACTH 4-9 analog (ORG 2766) on human performance', Physiology and Behavior, 23, 79-84.

Haaland, K. Y., & Delaney, H. D. (1981) 'Motor deficits after left or right hemisphere damage due to stroke or tumor', Neuropsychologia, 19, 17-27.

Halstead, W. C. (1947), Brain and intelligence, University of Chicago Press, Chicago.

Harley, J. P., Leuthold, C. A., Matthews, C.G., & Bergs, L.E. (1980) Wisconsin Neuropsychological Test Battery: T-score Norms for Older Veterans Administration Medical Center Patients, Matthews, Madison.

Hartman, D. E. (1988), Neuropsychological toxicology: Identification and assessment of human neurotoxic syndromes. Pergamom, New York.

Haxby, J. V. et al. (1986) 'Relations among age, visual memory, and resting cerebral metabolism in 40 healthy men', Brain and Cognition, 5, 412-427.

Houx, P. J., Vreeling, F. W., & Jolles, J. (1991) 'Rigorous health screening reduces age effect on Memory Scanning Task', Brain and Cognition, 15, 246-260.

Houx, P. J. (1991) Cognitive Aging and Health-related Factors, Doctoral thesis, University of Limburg, The Netherlands.

Jolles, J. (1991) The Netherlands Memory and Aging Programme, NESTOR Research Proposal, University of Limburg, The Netherlands.

Ligthart, G. J. (1989), The Immune System in Human ageing: Necessity of the Assessment of Health Status in Gerontological Studies, doctoral thesis, University of Leiden, the Netherlands.

Perlmutter, M., & Nyquist, L. (1990), 'Relationships between self-reported physical and mental health and intelligence performance across adulthood', Journal of Gerontology: Psychological Sciences, 45, 145-155.

Rowe, J. W., & Kahn, R. L. (1987), 'Human aging: Usual and successful', Sience, 237, 143-149.

Rabbitt, P. (1986), 'Memory impairment in the elderly', in P. E. Bebbington & R. Jacoby (eds.), Psychiatric Disorders in the Elderly, Mental Health Foundation, London.

Salthouse, T., Kausler, D. H., & Saults J. S. (1988), 'Investigation of student status, background variables, and the feasibility of standard tasks in cognitive aging research', Psychology and Aging, 3, 29-37.

Stones, M. L., Kozma, A., & Hanna, T. E. (1990), 'The measurement of individual differences in aging: The distinction between usual and succesful aging', in M. L. Howe, M. J. Stones, & C.J. Brainerd (eds.), Cognitive and Behavioral Performance Factors in Atypical Aging, Springer, New York, pp. 181-218.

Verhage, F. (1964), Intelligentie en Leefijd, doctoral thesis, University of Groningen, The Netherlands.

Welford, A. T. (1985) 'Changes of performance with age: An overview', in N. Charness (ed.), Aging and Human Performance, Wiley, Chichester, UK, pp. 333-369.