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Influence of Biological Age on Professional Efficiency: Communication I. Biological Age and Mental Efficiency

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Abstract—Biological age (BA) and mental efficiency (ME) were studied in truck drivers. The study demonstrated the features of the systemic organization of the functions that determine ME depending on the age and length of service. Premature age-related changes in psychophysiological indices were just "risk indicators" in truck drivers. However, long-term service was found to be an actual risk factor which accelerated the aging process. This work demonstrates the adequacy and high informative value of the approaches suggested to evaluate the aging rate by ME indices and the necessity of prophylactic measures aimed at preventing the premature aging of employees.

The evaluation of the biological age of an individual is a unique diagnostic method, aimed mainly at the quantification of the body's condition on the basis of its aging stage ("age-related deterioration") [1]. In other words, the evaluation of the biological age is a general biological (gerontological) but not nosological diagnosis, which does not rely on disease classification (or the concept of disease itself) [2, 3]. However, prenosological and nonnosological diagnosis is of primary importance in disease prevention and professional and social rehabilitation of "unhealthy" and sick subjects. This enables physicians to perform two tasks, i.e., theoretical (analysis of the contribution of various factors to the age-related decrease in vitality) and practical (detection of high-risk groups).

The heterochronous, heterotopic, heterokinetic, and heterocatephtenic character of the aging process and the resulting discrepancy between the chronological and biological age of an individual make it possible to widely use differentiated aging while evaluating the degree of vitality and the biological capacities of a human body [4–7].

Since the difference between the biological and calendar ages is a criterion of the aging rate, the biological age may be used to evaluate the influence of the conditions and character of work on the aging pace in employees who differ in age and length of service. This opens an approach to solving the problems of the impact of a complex of hazardous environmental factors, timely retraining, changing the work intensity and occupation, and creating a system of measures aimed at a prolongation of the able-bodied period in senior age groups.

At the same time, the general dependence of aging of the body on the whole and its various functions on the character of work has not been studied sufficiently [8].

The purpose of this work was a comparative evaluation of biological age on the basis of mental efficiency in two professional groups. This integral criterion reflects the influence of the features of the labor process on employees' health and may be used to control its condition.

METHODS

The test subjects were 296 males, including an experimental group of 148 drivers from a truck depot and a reference group of 148 employees (repair fitters and toolmakers) of the main workshops of the Santekhpribor plant, Kazan, which manufactures sanitation facilities. The groups were selected using the copy-pair method to equalize their distribution by calendar age, length of service, work schedule, education, marital status, and number of children. The test subjects were grouped according to their age (in decades) and length of service (in five-year increments).

Mental efficiency was evaluated by a complex of psychophysiological tests aimed at studying the attention, memory, and thinking functions. The tests included the following indices: immediate (IM) and working memory (WM), short-term memory index (STMI), mental productivity (Q), productivity index K, errors per 500 (C_1) and 200 (C_2) symbols, ability for classification (CL), ability to interpret proverbs (P), ability to choose synonymic and antonymic words (SA), ability for the method of elimination (MEL), ability for associations (A), complicated attention volume (CAV), and simple attention volume (T).

The short-term memory volume, which included immediate and working memories, was measured by the Muchnik–Smirnov method as the number of the stimuli (words and digits) recalled in the preset order after a single presentation [9].

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Table 1. Results of study of mental efficiency ($M \pm m$) in truck drivers, compared with the reference group

Indices (arb. unit)	Experimental group (N = 148)	Reference group (N = 148)	Significance of differences (p)
Immediate memory	11.523 ± 0.068	11.508 ± 0.061	>0.1
Working memory	10.438 ± 0.079	10.785 ± 0.097	<0.01
Short-term memory index	19.981 ± 0.21	20.997 ± 0.268	<0.01
Productivity index	1.824 ± 0.028	1.905 ± 0.027	<0.05
Mental productivity	76.321 ± 2.004	81.960 ± 2.132	<0.05
Errors per 500 symbols	7.911 ± 0.692	6.714 ± 0.512	>0.1
Errors per 200 symbols	3.164 ± 0.277	2.685 ± 0.205	>0.1
Ability for classifications	7.899 ± 0.273	9.669 ± 0.339	<0.0001
Ability to interpret proverbs	1.669 ± 0.125	4.655 ± 0.246	<0.0001
Ability to choose synonyms and antonyms	5.061 ± 0.172	7.122 ± 0.201	<0.0001
Ability for the method of elimination	0.453 ± 0.041	0.358 ± 0.039	<0.05
Ability for associations	8.041 ± 0.162	10.108 ± 0.210	<0.0001
Complicated attention volume	1.605 ± 0.066	1.907 ± 0.086	<0.01
Simple attention volume	0.047 ± 0.017	0.615 ± 0.040	<0.0001

The test subjects' mental productivity was studied by a modified method with time metering and V.Ya. Anfimov's letter correction tables.

The main qualitative and quantitative characteristics of attention (volume, stability, distribution, and switchover) were examined by a method of finding numbers in the Shul'te–Platonov "black–red tables" modified by V.V. Kryzhanovskaya, as well as by the number of the objects perceived simultaneously and within a limited time period using a tachistoscope [10].

The biological age was calculated from the mental efficiency indices for each test subject by the formula suggested by L.M. Belozerova using multiple stepwise linear regression [11]: BA based on ME of males = 127.41 – 9.43IM + 16.19WM – 8.02STMI + 7.48K – 0.64Q – 0.05C_1 – 0.16C_2 + 3.45CL – 0.39P – 2.78SA + 4.56MEL – 5.10A + 4.74CAV + 0.86T.

To form a data base of the physiological and psychophysiological studies, we developed a special Bioage program complex of seven main modules, realized in the CA-Clipper-5.01 language. The results were processed using modern methods of mathematical analysis (the Analysis, Stadia-4.5, Lotus 1-2-3 for Windows 5.0, and Lotus Approach for Windows 3.01 standard packages).

RESULTS AND DISCUSSION

Comparative analysis of the motility of nervous processes, based on the data concerning attention, mnestic functions, and speech and thinking activity, revealed significant differences both on the general level and in individual indices of mental efficiency between the experimental and reference groups (Table 1). On one hand, the study of the dynamics of the indices depending on age and length of service confirmed the heterochronous nature of the aging processes, and, on the other, it demonstrated their heterokinetic nature in each group.

The working memory volume decreased in both groups earlier and more rapidly than that of immediate memory. This agrees with the previous data [12, 13]. It is considered natural that this function weakens in males at ages between 50 and 70 [14–16]; in truck drivers, these phenomena are recorded at the ages of 40 to 49.

Our studies demonstrated that mnestic functions are subject to quantitative and qualitative changes related to age and length of service, such as a lower volume of memorized material, a slower memorizing process, and a downward trend in its accuracy. Initially, the test subjects of both groups found themselves weaker in memorizing the most complicated logic-semantic structures, while the simple and more habitual ones remained relatively intact. At the same time, the weakening of mnestic functions begins 10–15 years earlier in drivers than in other employees.

Correction tests demonstrated differences in the mental productivity levels between the experimental and reference groups, irrespective of age and length of service (p < 0.001–0.05). Notably, both the qualitative and quantitative deterioration of these indices was especially abrupt in the drivers with a length of service of 20 or more years from the age of 40.

The study of the dynamics of cogitative functions demonstrated a natural weakening of analytic–synthetic activity as the aging process progressed. However, the ability for classification weakened earlier in the 30- to 39-year-old drivers with a length of service of 10 to 14 years than in the younger ones with a shorter length of service (p < 0.001–0.05). Changes were found

Table 2. Influence of age and length of service on the mental efficiency indices in (I) truck drivers and (II) the reference group

Indices	*H* criterion (number of degrees of freedom)			
	age		length of service	
	I	II	I	II
Immediate memory	25.229(4)***	22.480(5)***	19.257(4)***	11.424(4)*
Working memory	31.128(4)***	25.482(5)***	17.110(4)**	16.535(4)**
Short-term memory index	21.974(4)***	19.939(5)**	10.567(4)*	12.966(4)*
Productivity index	6.416(4)	8.981(5)	3.363(4)	1.086(4)
Mental productivity	70.806(4)***	39.009(5)***	50.673(4)***	16.623(4)**
Errors per 500 symbols	25.512(4)***	14.811(5)*	26.208(4)***	14.648(4)**
Errors per 200 symbols	25.512(4)***	14.811(5)*	26.208(4)***	14.648(4)**
Ability for classifications	36.970(4)***	20.825(5)***	24.467(4)***	15.298(4)**
Ability to interpret proverbs	7.297(4)	22.363(5)***	3.889(4)	7.713(4)
Ability to choose synonyms and antonyms	22.995(4)***	13.621(5)*	10.752(4)*	5.767(4)
Ability for the method of elimination	1.688(4)	2.657(5)	5.030(4)	3.727(4)
Ability for associations	5.068(4)	3.375(5)	2.640(4)	2.106(4)
Complicated attention volume	26.401(4)***	33.650(5)***	15.990(4)**	21.083(4)**
Simple attention volume	2.850(4)	8.139(5)*	6.300(4)*	2.191(4)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

in other indices of logical thinking in the 40- to 49-year-old drivers with a length of service of 20 or more years. The indices of mental productivity and cogitative functions were significantly higher in the reference group than in the drivers, irrespective of age and length of service ($p < 0.001$–0.05), and decreased significantly only after the test subjects reached the age of 60.

Comparing the volume, stability, distribution, and switch-over of attention in both groups, we found that, in spite of a synchronous impairment of these functions in the ages from 40 to 49, the drivers demonstrated significantly lower indices than the reference group, irrespective of their age and length of service ($p < 0.001$–0.05).

Factor variance analysis confirmed that the psychophysiological indices that reflect mental efficiency deteriorate not only with age but also with length of service (Table 2). The influence of the latter was significantly stronger in the drivers than in the reference group ($p < 0.001$–0.05).

Notably, although age or length of service did not affect the ability for associations recorded in either group, the drivers showed a significant dependence for it on the work schedule ($H(4) = 11.853$; $p < 0.05$). It was lowest in those who worked on rotation, i.e., one working day was followed by two days off (7.653 ± 0.231 arb. unit), and highest in those who worked only in the daytime (9.636 ± 0.378 arb. unit).

The biological age calculated from the mental efficiency indices was an integral criterion that reflected the general condition of the psychophysiological functions and the degree of their age-related weakening. The comparison of the biological age dynamics depending on the ME with the changes in the calendar age showed that the physiological state of mental efficiency deteriorated insignificantly in the reference group. This process was more pronounced in the drivers, especially in those above 40 ($p < 0.001$). Statistically significant differences were found between the groups, irrespective of length of service ($p < 0.0001$–0.01). Biological age did not change substantially with length of service in the reference group. The functional state of the drivers' ME deteriorated abruptly after they drove trucks for 20 years ($p < 0.01$).

Factor variance analysis made it possible to evaluate the weakening of the psychophysiological functions that determine ME: in the drivers, it correlated with the age-related changes ($H(4) = 33.772$; $p < 0.0001$), length of service ($H(4) = 20.683$; $p < 0.001$), and education level ($H(4) = 14.108$; $p < 0.001$). In the reference group, this index depended significantly only on the education level ($H(4) = 18.964$; $p < 0.001$).

Correlation analysis showed that the mental efficiency parameters and the integral index of biological age depended on length of service as a driver (r_1) significantly more strongly than on chronological age (r_2). These parameters include immediate memory ($r_1 = -0.45$; $p < 0.05$; $r_2 = -0.31$; $p < 0.05$), working memory ($r_1 = -0.51$; $p < 0.01$; $r_2 = -0.43$; $p < 0.05$), short-term memory index ($r_1 = -0.45$; $p < 0.05$; $r_2 = -0.37$; $p < 0.05$), mental productivity ($r_1 = -0.71$; $p < 0.001$; $r_2 = -0.64$; $p < 0.01$), errors per 500 symbols ($r_1 = +0.45$; $p < 0.05$; $r_2 = +0.37$; $p < 0.05$), errors per 200 symbols ($r_1 = +0.31$; $p < 0.05$; $r_2 = +0.15$; $p < 0.05$),

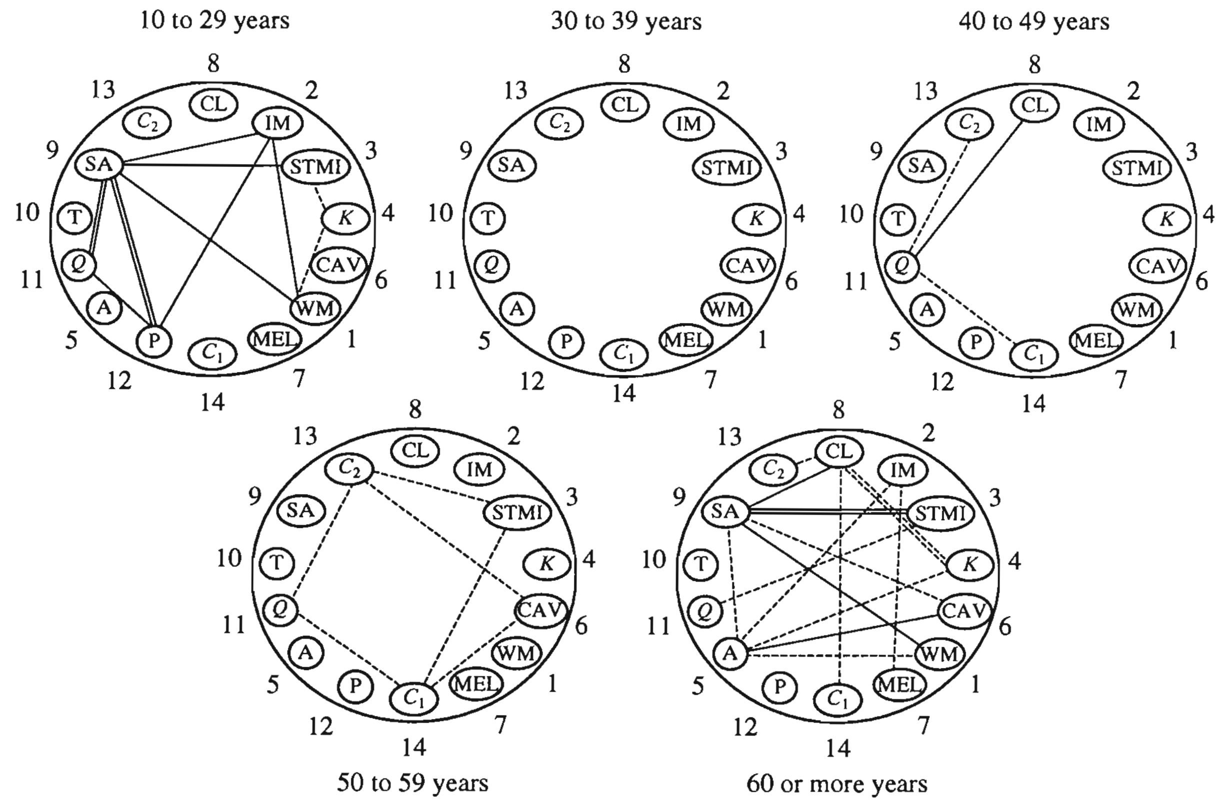

Fig. 1. Correlation constellations of biological age based on mental efficiency in truck drivers of various ages. Large circle, integral evaluation of biological age; small circles, specific psychophysiological indices. Continuous line, direct correlation $0.5 < r < 0.7$; dotted line, inverse correlation $|-0.5| < r < |-0.7|$; double continuous line, direct correlation $r > 0.7$. Numbers along the perimeter, numbers of indices (the smaller a number, the higher the multiple correlation ratio between the index and biological age). CAV, complicated attention volume; IM, immediate memory; STMI, short-term memory index; CL, ability for classifications; C_2, errors per 200 symbols; SA, ability to choose synonyms and antonyms; Q, mental productivity; T, simple attention volume; A, ability for associations; C_1, errors per 500 symbols; MEL, ability for the method of elimination; WM, working memory; K, productivity index; and P, ability to interpret proverbs.

ability to interpret proverbs ($r_1 = -0.33$; $p < 0.05$; $r_2 = -0.15$; $p < 0.1$), ability for classifications ($r_1 = -0.56$, $p < 0.01$; $r_2 = -0.45$, $p < 0.05$), ability to choose synonyms and antonyms ($r_1 = -0.47$; $p < 0.05$; $r_2 = -0.38$; $p < 0.05$), and biological age calculated from the mental efficiency indices ($r_1 = +0.49$; $p < 0.05$; $r_2 = +0.40$; $p < 0.05$).

These results show that a premature decrease in most of these psychophysiological indices of the drivers' mental efficiency is related not so much to their age as to their length of service. The notable positive correlation of the ME-based BA with the latter factor, which is stronger than with calendar age, again confirms the predominant influence of the labor process features on the aging pace.

The results of correlation and regression analysis became a basis for the correlation constellations that characterize biological age on the basis of mental efficiency (integral evaluation) depending on the drivers' age and length of service (Figs. 1 and 2, respectively).

It may be seen from Fig. 1 that the 20- to 29-year-old drivers show many correlations between the main mental efficiency parameters, which form two blocks. On one hand, strong and very strong correlations [$0.5 < |r| < 0.7$], [$|r| > 0.7$] existed between the cogitative function indices (ability for associations, ability to interpret proverbs, and mental productivity). The second block was formed by strong [$0.5 < |r| < 0.7$], [$-0.7 < |r| < -0.5$] direct and inverse correlations of indices of the intellectual–mnestic functions (immediate memory, working memory, short-term memory index) with the mental productivity index as the connecting element. At the same time, the blocks are connected by strong direct correlations [$0.5 < |r| < 0.7$]. This should be considered a sign of a more manifest general adaptation syndrome, when a driver's body adapts itself to the features of the labor process and unfavorable environmental factors that characterize his occupation.

In the next age group of 30 to 39, the number of functional correlations between the limiting indices goes down abruptly, combined with a weakening of the remaining correlations that is, functional correlations of the medium, high, and very high degrees are absent (Fig. 1). The mental efficiency indices that form two

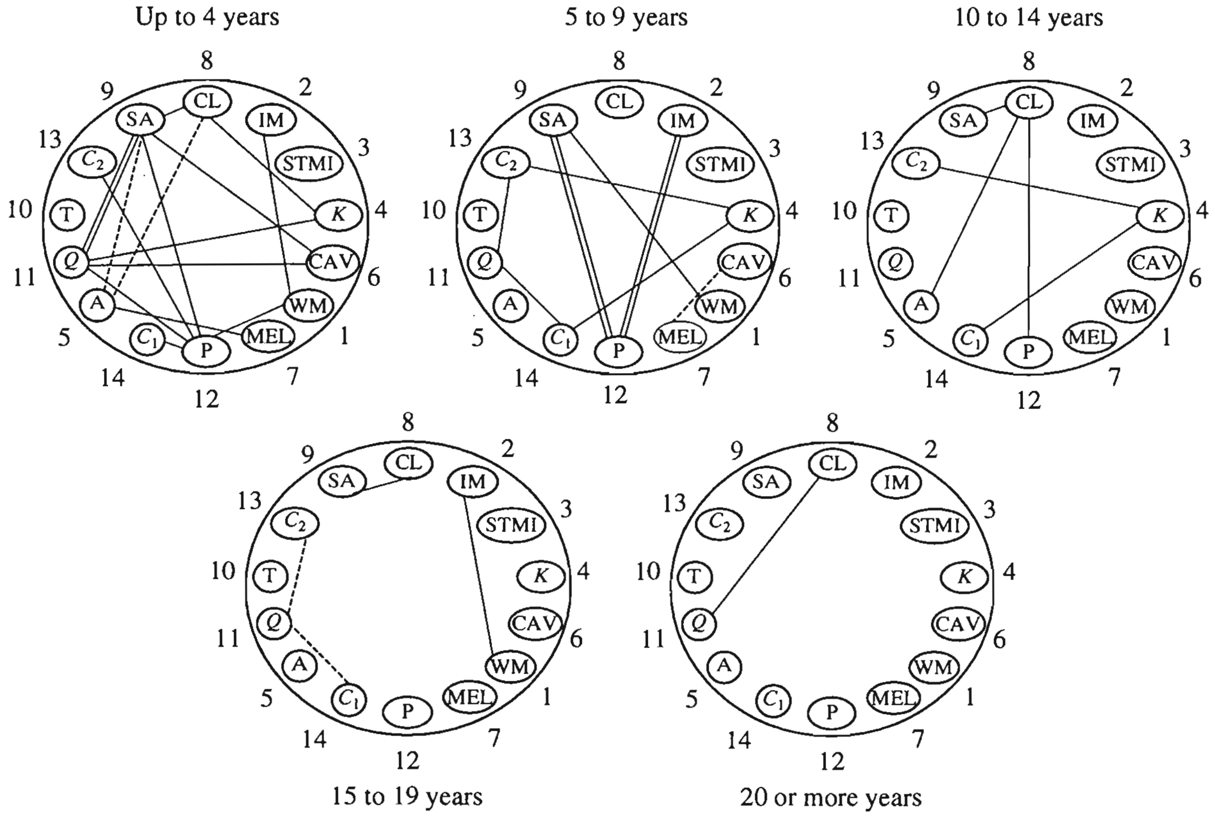

Fig. 2. Correlation constellations of biological age based on mental efficiency in truck drivers with various lengths of service. Designations as in Fig. 1.

interdependent blocks in the aforesaid group were significantly higher in the 20- to 29-year-old drivers than in the 30- to 39-year-old ones ($p < 0.001$–0.05). Thus, close correlations between the mental efficiency parameters at the ages of 20 to 29, which are signs of a manifest tension of the body regulatory systems and result in the weakening of the intellectual–mnestic functions, may be considered an intermediate period when a driver's body reaches a higher functional level of vital activity by the age of 30 to 39. This level may be treated as an optimum from the viewpoint of an adequate response of a driver's body to the impact of the "disturbant" environmental factors.

At the age of 40 to 49, a few direct and inverse correlations emerge again among the mental efficiency indices. This is an indicator of instability of the system, insufficiency of the earlier functional level, and the necessity of a transition to a new one.

In 50- to-59-year-old drivers, the number of correlations increases, reaching its peak by the age of 60 and more and spreading to almost all mental efficiency indices. This may be characterized as a transition of most of the drivers of this age to a higher functional level of vital activity and the attempt of their bodies as biological systems to retain the achieved level of vital activity at all costs, thus ensuring the appropriate professional efficiency level.

However, the weakening of the adaptive potential of some functions in the 60-year-old and older drivers who had not changed their occupation increases the number of functional correlations among the limiting indices which act as additional compensatory links and the degree of the participation of the central control circuits. This weakened the stability of the system on the whole, preventing the optimal reaction of the body to the "disturbing" environmental factors. In our previous works, we found "the effect of a healthy worker" among drivers [17], when unorganized occupational selection manifested itself in the dropout of the subjects with weaker health in the age groups of 40 to 49 and 50 to 59 years. Therefore, the drivers who continue working at the age of 60 and more demonstrate the formation of a new system whose structural stability enables them to retain the functional characteristics relying on emergency adaptation mechanisms, while the drivers with weaker health reach a turning point between the ages of 40 and 59: the body loses its ability for efficient adaptation, and the further evolution of the biosystem may be described as disadaptation. Thus, the body of the subjects of this age with initially low functional reserves and a low adaptive potential is characterized by inefficient mechanisms of homeostatic regulation.

As can be seen from Fig. 2, the dynamics of correlations between mental efficiency and length of service

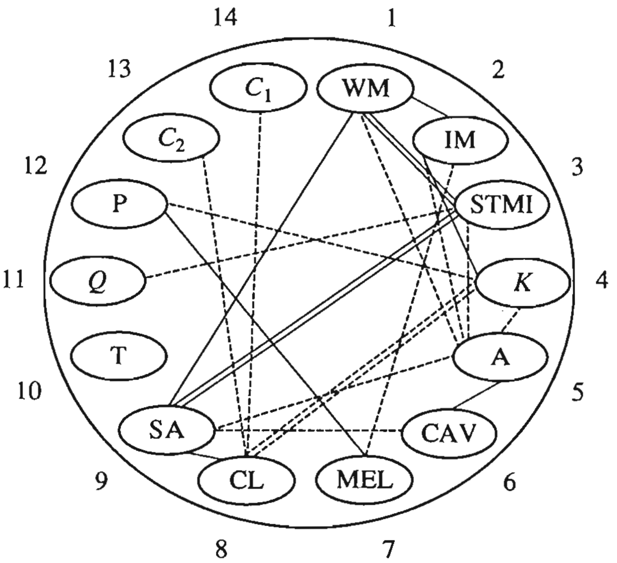

Fig. 3. Correlation constellation of biological age based on mental efficiency in truck drivers above 60 years with length of service of 20 and more years. Designations as in Fig. 1.

as a driver is entirely different. Most of the strong and very strong direct and inverse correlations are found in the individuals with a length of service of four or fewer years, who undergo the adaptation to the unfavorable labor conditions (usually in 20- to 29-year-old drivers). This is the only common feature with the age distribution of correlations. After working for five to nine years, the number of correlations decreases gradually. Only one of them is noted in the drivers who work for 20 or more years, i.e., that between mental productivity and the ability for classifications.

Hence, it may be assumed that as the length of service increases, a driver's body reaches the optimal adaptation stage, followed by the mobilization of the functional reserves with a transition to a higher functional level of vital activity. The maximum weakening of correlations in the group of the drivers who work for 20 and more years may be a testimony to reduced functional tension, a minimum number of compensatory links, and enhanced stability of the system on the whole.

This hypothesis may be correct only if length of service increases proportionally to the test subjects' age. However, we noted a predominance of individuals with a length of service of 10 to 14, 15 to 19, or even over 20 years (most of them became drivers during their military service) among the 30- to 39-year-old drivers. Forming a correlation constellation for drivers 60 years old and older with a length of service of 20 or more years (Fig. 3), we found a picture that was identical to that in Fig. 1. At the same time, most of the mental efficiency indices decreased considerably after 20 years of driving ($p < 0.001$–0.05). These results show that it is between the ages of 30 and 39 when drivers reach the peak of their professional efficiency due to an optimum regime of homeostatic regulation. It is the same period when employees are differentiated on the basis of their adaptive potential and functional reserves. Then, at the ages of 40 to 49 and 50 to 59 years, the employees with low adaptive abilities drop out and only those drivers continue working whose professional activity is supported and adjusted by numerous correlations on various levels of the central nervous system and other functional formations, including those supporting mental efficiency. This polyfunctional support enables them to perform the most difficult components of professional activity for a longer period with an insignificantly impaired mental efficiency. Thereafter, at the age of 60 or more, the functional state deteriorates, which is natural, and the efficiency of compensatory processes weakens, impairing professional efficiency.

Thus, as a driver's body adapts itself to new labor conditions, it develops numerous functional correlations to choose the optimum version of reacting to the "disturbant" environmental factors. When the adaptation process is completed, the number of limiting links decreases to the minimum that permits their adequate functioning in certain labor conditions. At the same time, the correlations and interdependences that formed in the beginning of the adaptation and became "superfluous," i.e., not required at the moment, do not disappear; they persist to form additional functional reserves.

As age and length of service increase, the impact of unfavorable environmental factors on a driver's body makes it activate the existing but latent connections, i.e., mobilize functional reserves.

Drivers' bodies may develop further in two ways:

(1) The body finds a way out from the existing situation by mobilizing the available resources, activating alternative adaptive mechanisms, and forming a new system of functional correlations, which enables a driver to discharge his duties to an extent and work for a definite but not very long period. At the same time, being far from an optimum because of too numerous limiting links, this system prevents the body from preserving its adaptive potential.

(2) Otherwise, morbid systems begin to form in the drivers whose bodies fail to form and/or mobilize the functional reserves or lose them for any reason. This growing mismatch between the biosystem and environment manifests itself in upsetting the dynamic equilibrium in the reaction to a complex of external and internal stimuli by changes in the output parameters and structure of their interaction. This should be considered a manifestation of an abnormality in the adaptation process. This category of employees "drops out," i.e., changes occupation, unless the current functional state is corrected in time by optimally selected adaptogens and geroprotectors, including cytamines and cytomedins.

We believe on the basis of our results that, depending on the labor conditions, the neuroregulatory mechanisms that take part in the complicated process of individual adaptation may include various physiological reactions, depending on the character of the extreme factors that affect the body. Reaching a similar level of the regulated parameters, drivers of different ages and with different lengths of service demonstrate uneven changes in various links of the regulatory system and differ in the condition of the functioning systems. In addition, the age-related changes that limit drivers' mental efficiency narrow the range of the functional abilities of their bodies and weaken the reliability of the "driver–vehicle–traffic environment" system.

The influence of age on mental efficiency may have a cumulative effect; i.e., the aging of the "supporting" systems is an additional factor that reduces the efficiency of professional activity, even when the loads are less than in the youth. This means that the prevention of employees' premature aging should be aimed to not only the "system-forming" elements but also to the "supporting" elements and additional concerns.

CONCLUSION

(1) Early weakening of some intellectual–mnestic functions and accelerated aging as revealed by mental efficiency in 40- to 49-year-old truck drivers with a length of service of 15 to 19 years make it possible to consider this group a "critical contingent with premature aging phenomena."

(2) The weakening of mental efficiency with age and length of service is counterbalanced in closed populations by the spontaneous dropout of the functionally weaker members of the "critical contingent."

(3) The evaluation of the strength of correlations between mental efficiency indices and their dynamics related to age and length of service, combined with biological age, reflects the trends of the compensatory–adaptive reactions of the human body under a prolonged impact of unfavorable factors of the professional environment.

(4) Biological age calculated on the basis of mental efficiency in individuals with different motor regimes and types of labor is a key to a differentiated evaluation of the functional reserves and the degree of the depletion of the adaptive mechanisms, which may be corrected in time by geroprotectors.

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