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An analysis of some attributes of the dynamics of mental processing

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On a sample of 458 candidates at the Faculty of Transport and Traffic Engineering 8 tests of cognitive abilities were administered: 4 classical paper-and-pencil tests and 4 chronometric tests of complex reaction measurement type. Out of classical tests, two power tests were administered (according to the traditional classifications of psychological tests): Domino test of intelligence and Test of spatial visualization, as well as two speed tests: Test of mental mobility and Test of attention/vigilance. Out of chronometric tests, administered were the tests from electronic CRD series: Test of convergent thinking, Test of spatial visualization, Test of simple visual orientation and Test of operative thinking.

The study sought to examine whether there is a common source of variance among the allied indicators of the dynamics, i.e., the speed and stability of mental processing, when taking different types of tasks, differing also in the level of complexity on chronometrically devised cognitive CRD tests. Further, an attempt was made to find out how and to what extent these attributes of the dynamics of mental processing, contribute to the total time scores on chronometrically devised cognitive tests, on the one hand, and participate in the structure of indicators of efficacy on classical cognitive tests of speed and power, on the other hand.

The results showed that the speed as well as the stability of mental processing in all chronometric tests were highly correlated with the total time spent taking the test, whereas the correlation between the two attributes proved to be low. Two principal components of the dynamics of mental processing were extracted. The results point to the existence of mutually independent general attributes of the dynamics of mental processing, since the indicators of speed were saturated merely by the first, and the indicators of stability by the second principal component. The analysis suggests that the variances of the success on classical power tests (paper-and-pencil tests) are determined in part by the features of dynamics of mental processing as well.

Is it possible to discover a mechanism or a principle underlying human cognitive ability regardless of the differences in the structure and mutual relationships among various subsystems of the brain? Is there a unique principle that the brain uses while performing higher or more complex cognitive functions? These questions, called for by G. Edelman (Edelman, G.M. & Mountcastle, 1978) in seventies of the last century, are still open despite the expeditious development of research techniques and technologies, as well as modern attainments in informatics regarding data gathering and data analyses procedures.

Likewise, there are still other open questions: what are the basic dynamic characteristics of the functioning of higher brain structures mechanisms? What are the behavioral features of these characteristics, and are there common attributes of the dynamics of functioning of hypothetical brain structures mechanisms wherein process manipulations of various mental activities take place (Drenovac, 1994): perceiving, differentiation, recognition, orientation, symbolic manipulation (counting), understanding relations, concluding, decision making, managing etc.?

Characteristics of the dynamics of brain functioning, i.e., speed of interchange, strength and mutual balance of basic neurophysiological processes of excitation and inhibition, which were studied extensively in Moscow 'Brain Institute' and within the research by Pavlov's followers (Nebylycin, 1976), are still inconclusive, since there are no reliable behavior indicators of cortical dynamics and, in that context, dynamics of mental processing.

Manifestations of dynamical features of the brain functioning in accomplishing higher order functions, that is, the attributes describing mental processing, can nowadays be studied on different levels. Numerous methods and techniques for this kind of research can be divided roughly into invasive and noninvasive. Invasive techniques, such as implementation of electrodes into neurological substratum enable more detailed and complete data for neurophysiological research on brain functioning, whereas noninvasive

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techniques, such as EEG, EP, as well as various types of psychological tests, offer indirect data on the ways and the efficacy of mental processing, and thus more generalized interpretations of the characteristics of the brain functioning dynamics (Marx & Cronan-Hilix, 1987).

Research on behavioral features of the attributes of the mental processing dealing with characteristics of the mental functioning in the process of taking psychological ability tests is a subject of cognitive psychology and exceeds the framework of neurology and neuropsychology (Medvedev & Pahomov, 1989).

During the last quarter of the 20th century, in the area of cognitive psychology there was an increased interest for the research on the relationships between characteristics of the brain functioning dynamics and the efficacy of mental processing. This particularly applies to the research relying on the hypothesis on the relations between the speed of neuronal conduction and cognitive efficacy (Sternberg & Kaufman, 1998). Such an approach is present in research on the relationships between complex reaction time, that is, time of psychomotoric response and IQ (Jansen, 1979), research on speed of lexical recognition and verbal abilities (Hunt, 1978), as well as in research on inspection time and IQ (Nettlebeck, 1982). Nevertheless, in these sorts of research the problem of ascertaining the behavioral features of the dynamics of neurological mechanisms functioning is not adequately resolved. Sternberg tried to resolve the question of behavioral indicators of the dynamics of neuronal processes by parceling out complex psychometric task into elementary components of information processing. Other researchers, instead of utilizing 'raw' time of item response as a dependent variable, used to derive measures of psychophysiological functions after repeated iterations of setting similar items (cf. Deary & Stough, 1996). However, all these studies deduce the problem of the dynamics just to the speed of processing.

Electronic CRD series of cognitive tests (Drenovac, 1994) is one of rather few cognitive tests batteries which, along with basic information on the speed of mental processing, offer data on the peculiarities of mental functioning in the process of taking psychological tests, as well as the data on the attributes of dynamics and the functional disturbances during the process of mental activities (provoked by test). Four tests from the CRD series were administered in this research.

PROBLEM

Potential problem of this study is to find an answer to a question: Are there manifestations of general features of the dynamics of mental processing, and if so, are these features mutually independent functional characteristics of the brain? Clearly, the results of this study can give just indications of the answers.

At the operational level, this study seeks to examine: is there a common source of variance among allied indicators of the dynamics, i.e., speed (TMIN), and stability (UB) of mental processing when taking different types of tasks, differing also in the level of complexity on chronometrically devised cognitive CRD tests; likewise, how and to what extent the attributes of the dynamics of mental processing contribute to the total time of solving chronometrically devised cognitive tests (UKT), on the one hand, and participate in the structure of indicators of success on classical cognitive tests of speed and power, on the other hand. In this regard following specific research questions were formulated:

1. To what extent are the total times (UKT) of taking particular chronometrically devised cognitive CRD tests determined by the speed - represented by indicators of the shortest time of answering the items in particular test (TMIN), and the stability of time of answering individual items in these tests, which is represented by derived indicators of wasted time (UB)?
2. Could the sources of variance of the shortest time responses (TMIN) as well as indicators of 'wasted time' (UB) be identified in the administered CRD tests?
3. Which amount of variance in indicators of success on the administered classical tests of speed and power can be accounted for by hypothetical attributes of the dynamics of mental processing (mental speed represented by TMIN indicators and stability of processing represented by UB indicators)?

METHOD

The research was done on a sample of 458 male candidates for the studies at the Faculty of Transport and Traffic Engineering, University of Zagreb. Participants were tested individually using four chronometric tests from the electronic CRD series of cognitive tests, and in groups by four classical paper-and-pencil cognitive tests, two of which being power tests and the remaining two tests of speed (according to traditional test classification).

Traditional classification of psychological tests on power and speed tests rests on assumption on mutual independence of the attributes of efficacy of mental processing. Accordingly, 'mental speed', i.e., item response time in tests indicate the speed of functioning of the mechanisms of mental processing, whereas the number of correct answers on items varying in difficulty level reflects 'mental power', that is, ceiling 'difficulty level' or the complexity of mental activity that a person can master.

Following CRD test were administered: Test of convergent thinking (CRD11), Test of spatial visualization (CRD13), Test of visual orientation (CRD21), and Test of operative thinking (CRD41). Two classical power tests - Intelligence test D48 (Pictot's adaptation of Anstey Domino test) and Test of spatial visualization (BTIPR; Slovenian Battery of Tests in Industry), as well as two speed tests were also administered: Test of mental mobility (MSTA) and Test of attention/vigilance TP-2 (a variant of Pieron-Toulous Test).

While the classical ability tests used in this study are well known, since they are frequently and widely utilized in applied settings, tests of CRD series are relatively unfamiliar, although they have been used extensively for the purposes of psychological diagnostics as well, and even more as the instruments in various often interdisciplinary research (Bele-Potočnik & Drenovac, 1987). Therefore, they are described here in some more details.

CRD series of cognitive tests is consisted of 38 standardized tests along with a generator enabling the composing of an infinite number of tests for the measurement of cognitive functions and psychomotoric reactions of varying complexity level. Tests are conceived as measures of complex reactions where the answering time (latent period) and accuracy are measured in each individual test item. The answers are recorded in appropriate protocols, computed and analyzed automatically and arranged in standardized output list.

Particular CRD tests items are given in a form of individual signals or as combinations of visual and auditory signals presented on signal tables of the CRD instrument or via speakers. The answers (reactions) are given by pressing or releasing one or a combination of buttons or pedals (by one or more limbs) on the command part of CRD instrument.

CRD electronic system of psychodiagnostic instruments is devised in 1968 in relay technique, and thus far has passed through four developmental phases initiated by the need for continuous improvement of hardware and software according to the actual knowledge in the domains of electronics and informatics. It contains 4 electronic instruments, PC, printer, three packages of operational programs and a test generator (Figure 1).

Numerous studies have been conducted on symptomatic, discriminant and prognostic validity of 38 standardized CRD tests, as well as the evaluations of reliability of performance indicators and functional characteristics of mental processing using the multiple retest method (Drenovac, 1994). These tests are grouped into following categories: tests of perceptive abilities (measuring perception, discrimination, recognition, visual orientation, and spatial visualization), mnemonic tests (short-term memory and learning), and tests of reasoning (operative thinking, reasoning, and problem solving).

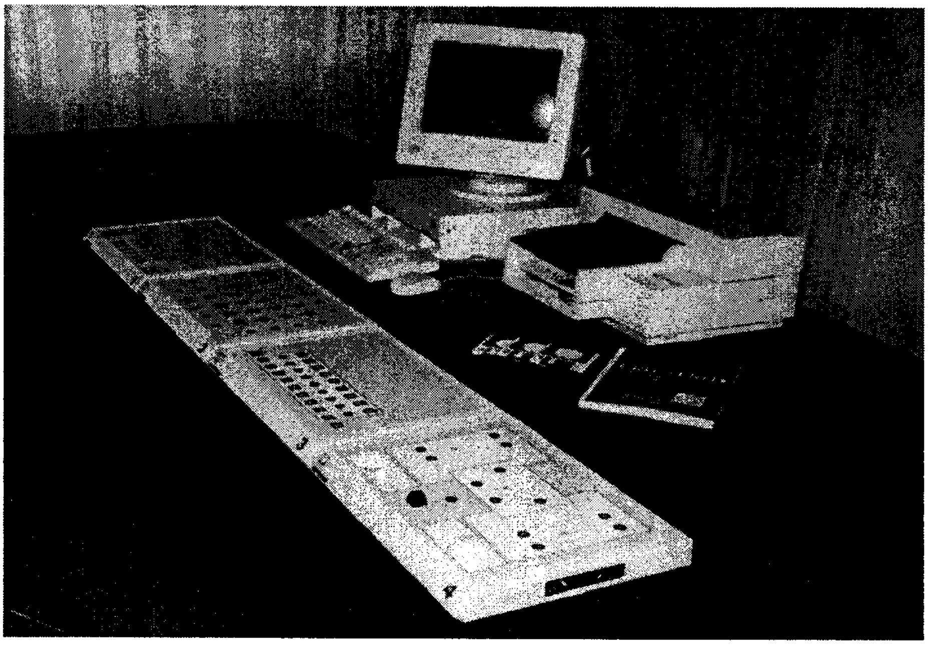

Figure 1. CRD System. The figure presents the fourth version from 1994, produced in 'Telespecial', Zagreb.

Output list of individual scores and indicators of the way of answering on particular test contains the data on: time (total time of taking the test; average, minimum, and maximum time of responding on individual items; total and average time of false item responses; total and average time of item responses following an error), number and position of errors, stability, i.e., variability of response time (balast or total wasted time, and partial balast in sequences as a function of taking the test), as well as the data on indicators of functional disturbances (dissociation, regression, perseveration).

Figure 2 presents the logic of derivation of partial chronometric indicators of the efficacy and the extraction of 'wasted time' from (latent period of) time spent on each individual item (Tz) in particular CRD test (Drenovac, 1995).

Out of the available original or derived chronometric indicators of the efficacy, dynamics, and style of answering the test items as a function of time spent on each of the administered CRD tests, only three indicators were analyzed in this study:

- total time of taking the test (UKT),
- the shortest time of answering an item in a particular test (TMIN), and
- indicator of stability (UB).

UB indicator of stability represents the sum of differences between the time spent on each individual item in a particular test (Tz) and the shortest time of answering an item (TMIN) in that test (UB=ΣTz-TMIN). It is considered to be total time of fluctuation or 'wasted time' in answering the items of particular test.

Statistical data analyses were performed using Statistica 4.5 program package.

RESULTS

First statistical analyses included correlations of indicators of the dynamics of mental processing, that is, maximum speed (TMIN) and stability (UB) of answering the items on each particular test, with the total time of taking the corresponding test (UKT), as well as correlation between the two indicators of the dynamics of mental processing.

Correlations of TMIN and UB with the total time (UKT) spent answering corresponding tests are presented

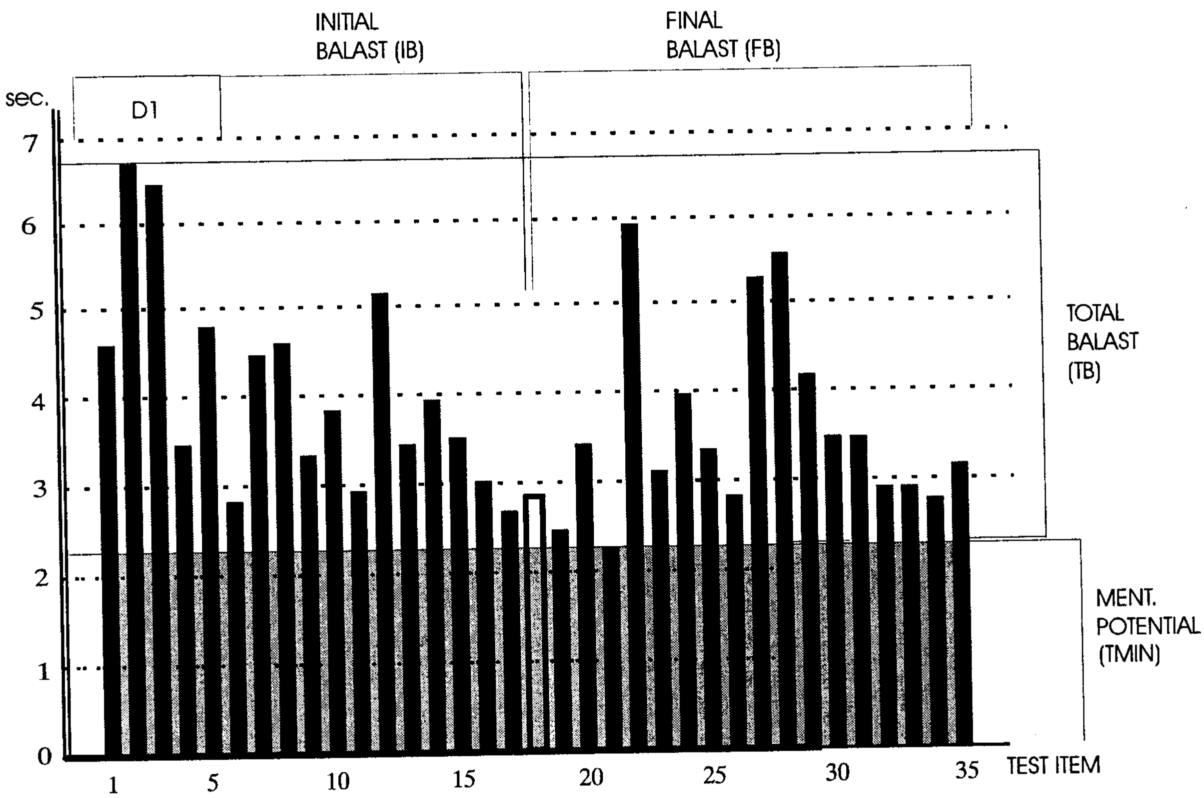

Figure 2. Rationale of extraction of indicators of the dynamics of mental processing based on tests from CRD series

Table 1

Correlations of speed (TMIN) and stability of answering the items (UB) with the total time of taking particular CRD test (UKT)

UKT	TMIN	UB	TMIN:UB
UKT 11	0.70	0.73	0.17
UKT 13	0.40	0.79	0.21
UKT 21	0.70	0.67	0.28
UKT 411	0.49	0.83	0.12

Note. N=458; all coefficients $r \geq 0{,}1198$ are significant at p<0.01.

Table 2

Parameters (M, SD) of indicators of the dynamics of mental processing in CRD tests

VARIABLE	*M*	*SD*	*N*
TMIN 11	2.00	0.31	458
UB 11	54.16	27.02	458
TMIN 13	0.96	0.11	460
UB 13	141.24	222.98	460
TMIN 21	0.79	0.12	423
UB 21	16.67	18.99	423
TMIN 411	0.43	0.08	405
UB 411	24.06	14.91	404

Note. N=458; all coefficients $r \geq 0{,}1198$ are significant at p<0.01.

Table 3

Correlation matrix of hypothetical indicators of the dynamics of mental processing in CRD tests

VARIABLE	TMIN 11	UB 11	TMIN 13	UB 13	TMIN 21	UB 21	TMIN 411	UB 411
TMIN 11	1.00							
UB 11	0.16	1.00						
TMIN 13	0.33	0.13	1.00					
UB 13	0.12	0.37	0.21	1.00				
TMIN 21	0.38	0.25	0.49	0.19	1.00			
UB 21	0.20	0.27	0.20	0.29	0.28	1.00		
TMIN 411	0.22	0.11	0.33	0.15	0.39	0.15	1.00	
UB 411	0.25	0.27	0.20	0.20	0.32	0.61	0.12	1.00

Note. N=458; all coefficients $r \geq 0{,}1198$ are significant at p<0.01.

in second and third column of Table 1, and their intercorrelations are given in the fourth column.

The results show that the shortest time of answering the items (TMIN) and total stability (UB) the correlations are rather low CRD tests, whereas both of these indicators highly correlate with the total time of taking the particular test. That means that the total time spent answering each individual test (UKT) is composed of two relatively independent components.

Principal components analysis with biquartimax rotation was performed in order to account for common sources of variance in indicators of the dynamics of mental processing. Descriptive statistical data of the indicators of dynamics of answering the items in particular CRD tests, correlation matrix, and the rotated factor matrix obtained are given in tables 2, 3, and 4.

As can be seen from Table 2, means and standard deviations of the results obtained on the four tests vary in a large range which points to the differences in complexity of mental processing when answering the items from different tests. The shortest time averages (TMIN) vary from 0,439 seconds for the Test of operative thinking (CRD 411) to 2,0065 seconds for the Test of convergent thinking (CRD 11), and the standard deviations vary in range from 0,0885 for the Test of operative thinking, to 0,3146 in the Test of convergent thinking (CRD 11). The parameters of stability indicators (UB) vary in even larger range. Averages of the 'wasted time' vary from 16,679 seconds in the Test of simple visual orientation (CRD 21) to 141,247 seconds in the Test of spatial visualization (CRD 13), and the standard deviations vary in range from 14,918 in the Test of operative thinking (CRD 411) to 222,988 in the Test of spatial visualization (CRD 13). The obtained ranges illustrate the magnitude of differences in the complexity of mental activities evoked by the items from particular CRD tests, which is quite clear having in mind that all CRD tests used in this study are of the same length (35 items each).

Table 4

Principal components of the indicators of the dynamics of mental processing

VARIABLE	BIQUARTIMAX NORMALIZED FACTORS		COMMUNALITIES From 2 Factors
	Factor 1	Factor 2	
TMIN 11	0.18	**0.61**	0.4023
UB 11	**0.64**	0.09	0.4122
TMIN 13	0.12	**0.76**	0.5914
UB 13	**0.58**	0.12	0.3560
TMIN 21	0.27	**0.75**	0.6429
UB 21	**0.79**	0.13	0.6429
TMIN 411	0.01	**0.69**	0.4809
UB 411	**0.76**	0.16	0.5993
Eigenval	2.8352	1.2924	
% Tot Var.	35.440	16.155	

Table 5

Principal component analysis of the indicators of power and dynamics of mental processing

VARIABLE	BIQUARTIMAX NORMALIZED FACTORS		COMMUNALITIES From 2 Factors
	Factor 1	Factor 2	
TMIN 11	0.18	**0.65**	0.4567
UB 11	**0.64**	0.04	0.3896
TMIN 13	0.18	**0.69**	0.5071
UB 13	**0.68**	-0.00	0.4305
TMIN 21	0.27	**0.72**	0.5694
UB 21	**0.70**	0.14	0.5107
TMIN 411	0.04	**0.58**	0.3459
UB 411	**0.65**	0.17	0.4468
D48	**-0.68**	-0.29	0.5033
BTIPR	**-0.64**	-0.21	0.4228
MSTA	-0.03	**-0.47**	0.2279
TP (2T)	**-0.36**	-0.28	0.1709
Eigenval	2.9079	2.2088	
% Tot Var.	24.23	18.41	

Correlation matrix given in Table 3. points to the low, but mostly statistically significant relationships among the similar indicators of the dynamics of mental processing of the different sorts and unequally complex cognitive material. Principal component analysis revealed two main components of the dynamics of mental processing. Their structure rotated to the biquartimax position is presented in Table 4.

All indicators of the stability of time spent in answering the items (UB) are saturated by the first principal component, which could therefore be named as factor of stability of mental processing. All indicators of the shortest time of answering (TMIN) are saturated by the second principal component, which could therefore be named as factor of speed.

Few comparative studies dealt with research on main sources or components of speed of mental processing and the power of individual mental potential. An attempt of such a comparative analysis is presented in Table 5.

Table 5 presents the results of principal component analysis performed on the indicators of mental capacity represented by the scores obtained in classical tests of cognitive abilities - D48 and BTIPR, and the indicators of speed of mental processing represented indirectly by a number of correct answers in tests MSTA and TP (2T), along with chronometric indicators of the dynamics of mental processing.

Indicators of performance on typical tests of power of mental potential (Intelligence test D-48 and Test of spatial visualization - BTIPR) are saturated to a similar degree by the first principal component, named as the component of stability of mental processing according to the previously presented results. Bipolarity of this component suggests that greater efficacy in classical power tests or greater mental capacity is accompanied by a greater stability, that is, by a lesser amount 'wasted time' in mental processing. These findings point to the common source of variance in both types of indicators of efficacy of cognitive functions.

Second principal component, interpreted as the component of speed and joining indicators of the shortest time scores in particular tests (TMIN), is considerably related to indicators of achievement on classical Test of mental mobility (MSTA).

CONCLUSIONS

The main conclusions to be drawn from this study are the following:

- Total time scores (UKT) in all chronometrically conceived cognitive CRD tests used in this study are considerably determined by two mutually independent components - the shortest time (TMIN) and the amount of 'wasted time' (UB).
- The dynamics of mental processing is determined by two orthogonal principal components: the component of speed, significantly affecting the indicators of the shortest time of answering the items (TMIN) in each individual test, and the component of stability, which saturates all indicators of fluctuations in time spent on items (UB) in the administered CRD tests. In different tests of CRD series these indicators represent the dynamics of mental processing of different cognitive material in terms of contents and complexity. Therefore, the obtained components are likely to explain similar attributes of the dynamics of functioning of neurological substratum underlying mental processing mechanisms.
- Principal components of the dynamics of mental processing derived from CRD test scores can account for parts of variance in power tests, suggesting that the mental capacity is not completely independent from the dynamics of mental processing.

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