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THE BASIC PARAMETERS OF HUMAN INFORMATION PROCESSING: THEIR ROLE IN THE DETERMINATION OF INTELLIGENCE

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Summary—Information psychology deals with information processing in humans which is measured in terms of time units (sec) and information units (bits) and is described by relatively simple models. The model of psychostructure is crucial. It adequately refers to information processing which runs as sequential dichotomous decisions on a 'yes–no' or an 'on–off' basis. The information unit 1 bit is allocated to each decision.

Three basic parameters are important in central information processing: (1) The information flow to the short term storage C_K (15.0 ± 3.1 bit/sec in adults). (2) The duration of presence (retention in primary memory) = T_R (5.4 ± 0.8 sec in adults). (3) The basic speed of learning C_V (depending on the time to retrieval: 0.01 to 1.00 bit/sec in adults). These capacities increase continuously from childhood to adulthood. Within each age group there are remarkable individual differences which exceed variations of biological variables such as body length or brain weight by far.

The prerequisite of information psychological measurement is to determine the information content of the stimuli and the reactions and to measure the time between the stimulus and the response. Based on this it is shown that the basic parameters are unspecific, because the type of information, the sensory modalities and the repertory of signs do not alter the results. Besides, the parameters are independent of each other and reach the level of a ratio scale. According to other concepts and other empirical findings, C_K and T_R determine the intelligence quotient including the vocabulary while C_V corresponds to mechanical learning. Tests for these parameters are given.

1. INTRODUCTION

In the German literature, information psychology emerged immediately before the sixties (Frank, 1959). It spread rapidly in the fields of psychology and even more in the field of educational subjects (Weltner, 1973).

The function of information psychology is to describe, explain or predict information processing in humans. These processes are measurable principally in terms of time units (sec) and information units (bits) and are described by relatively simple models. Therefore they reach a high level of precision and can be measured at a higher level of the metric scale. But these advantages in methods are not enough for the successful application of information psychology in human sciences. The concrete model of psychostructure proposed by Frank (1959, 1969) proved to be the crucial point for further scientific developments, and promises to be a fruitful tool for scientists. We have considered the possibility that the confused concepts of intelligence (Langeveld, 1967; Brand, 1988) can be substituted, re-interpreted, or at least based on information psychological models. Before presenting the differential aspects of intelligence we will describe the basis of general information psychology.

We will present the skeleton models and results and a simple test procedure for the basic parameters of information processing. Their historical roots, fundamentals and the actual experimental procedures for their investigation, as well as practical and theoretical problems and benefits, are discussed more fully in further papers. This concerns in particular the parameter 'information flow to short term storage', and the closely related concept 'basic period of information processing', which seems to be the most important information psychological development at present (Lehrl and Fischer, 1988).

2. GENERAL INFORMATION PSYCHOLOGY

The general model of information psychology refers to the sites of information processing within the model of psychostructure as well as to its directions and the magnitudes of its capacities.

The attribute 'general' indicates the fact that the functions and structures dealt with are present in all organisms (in this case in humans). Usually the estimates of magnitudes are the mean values of the reference population and variations are neglected because they concern differential and psychopathological aspects.

2.1. *Information psychology limited to controlled information processing?*

It is uncertain whether the information psychological models have such a general validity to concern all modes of information processing, such as verbal, numerical, spatial, musical, gustatory etc. Actually, at present the information psychological models and methods of measurement are mainly applied to verbal–numerical information processing (Weltner, 1973). This may be due to properties of the object which can be more or less suited for information psychology. The different suitability may agree with the distinction between the so-called 'automatic' and 'controlled' information processing systems (Shiffrin and Schneider, 1977), whereby the latter is crucial for verbal communication. According to such concepts it runs in a sequential and dichotomous mode in contrast with automatic information processing (analogous and parallel processing; tactile, figural mode of information; unit: items instead of bits). The term 'dichotomous' means that the processes occur on a yes–no or an on–off basis (Shands, 1959). Additionally it is claimed that controlled information processing is verbal or numerical and requires consciousness and effort. The adequate measurement of basic parameters requires the allocation of information unit 'bit' and the chronological unit 'second (sec)' to the stimuli and the responses. Methods of psychological measurements are discussed in Section 4.1. If these properties of the controlled information processing system (sequential, binary) are indeed found, information psychology has an ideal method. Automatic information processing, however, the units of which are conceived to be items analogous to stimuli, might be described by different comparable methods of measurement. At any rate, the following model of psychostructure should be adequate from the viewpoint of controlled information processing. But some favourable results on information psychological parameters which are measured by non-verbal methods, such as 'picture fusion' (cf. Section 4.1; Lehrl and Fischer, 1988), raise doubts about the necessity to restrict the information psychological models to controlled and therefore verbal–numerical information processing.

Even if the validity of the following model of psychostructure should be limited to controlled information processes, it is useful because of its conceptual and operational simplicity, and because it explains a great deal of the apparently complex cognitive efficiency in conventional intelligence tests and orientation in the environment.

2.2. *The model of psychostructure*

Figure 1 shows the psychologically most essential components of the model of psychostructure.

From the environment or body milieu, about 10^{11} bit/sec are stimulating the sense organs. The sensory nerves transfer these via the modality-specific sensory registers to the accommodator which in turn filters the magnitude of incoming information down to 15 bits/sec on an average in adults. This capacity is the so-called 'information flow to the short term storage C_K'. It differs inter-individually as other information psychological parameters do too. Their variations are treated under Section 3.2.

The accommodator has several tasks. As a filter it selects information according to the motivational state of the organism. Likewise, it directs attention to the arriving information and attempts to approximate the subjectively expected probability to the objectively given probabilities of events. Finally it transforms items from the sensory registers or long term memory to dichotomous sequences, i.e. 15 binary units/sec on an average.

Information that has passed the accommodator goes into the short term storage (= primary memory). As has been mentioned, the information flow of adults is 15 bits/sec. It is retained in primary memory about 5 to 6 sec (average adults). This is the 'duration of presence T_R' (Frank, 1959, 1969). According to Frank the total capacity of the short term storage, comprising the two elementary components T_R and C_K, amounts to: K_K (bit) = T_R (sec) × C_K (bit/sec). In other words, the short term storage K_K is the central information processing unit. Average adults have the capacity of 80 bit.

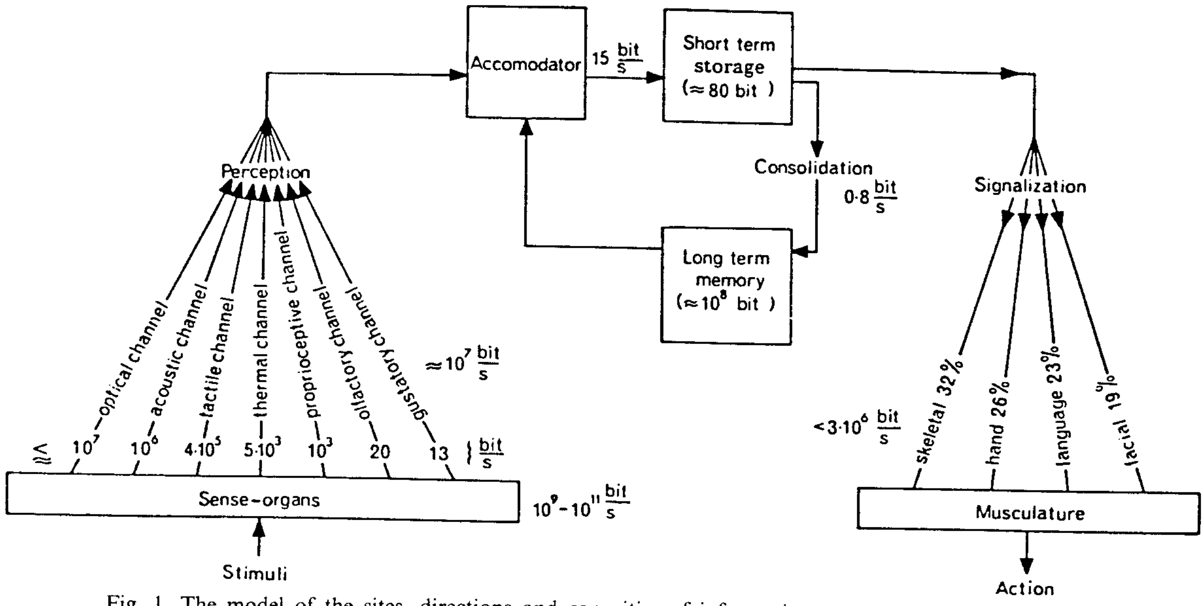


Fig. 1. The model of the sites, directions and capacities of information processing. The estimates of magnitudes are average values of adults.

The short term storage is the central unit for the processing of information. It is the site where the acts of discrimination and formation of supersigns take place. A portion of the information, that is 0.4 to 1.0 bit/sec, flows to the long term memory (= secondary memory) where it is stored for minutes, hours, days, months, or even years (the parameter is the basic learning speed C_V). Afterwards it may be retrieved into the short term storage via the accommodator.

3. DIFFERENTIAL INFORMATION PSYCHOLOGY

Variations of sites and directions of information flow which would belong to differential information psychology hardly occur. Therefore differential information psychology will be treated from the point of view of varying intra- and interindividual capacities.

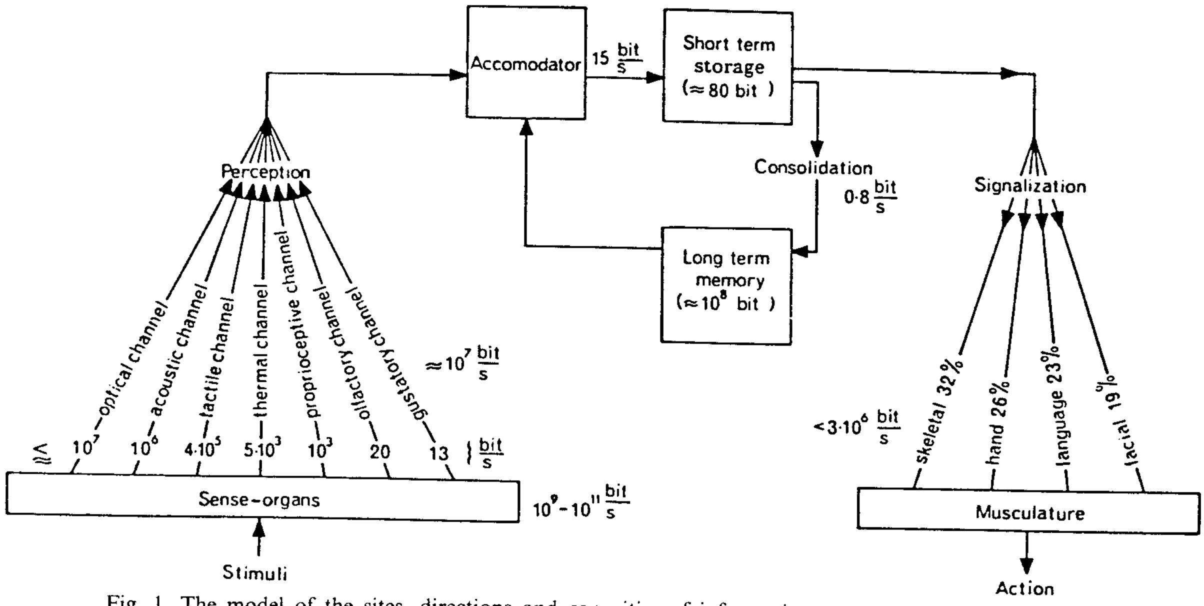
3.1. Development of basic parameters

All the above presented magnitudes are mean values in adults. Measurements in children and juveniles by Riedel (1967), De Groot (1974) and Dobmann-Murrmann (1980) give the values shown in Table 1.

The partial decrease of the parameters from 9 to 11 yr is probably related to the fact that some of the pupils left the elementary schools for secondary schools at the age of 10. The most important conclusion to be drawn from the development of these parameters is that they increase continuously

Table 1. Average parameters of information psychology in 7- to 15-year-old students (from Riedel, 1967). Values of C_V of university students were not available

	Parameters of information psychology			
Age (yr)	T_R (sec)	C_K (bit/sec)	$K_K = T_R \times C_K$ (bit)	C_V (bit/sec)
7	3.60	9.17	33.01	0.19
8	3.73	10.00	37.30	0.24
9	4.30	11.20	48.16	0.24
10	4.33	10.88	47.11	0.22
11	4.48	11.56	51.79	0.26
12	5.41	13.18	71.30	0.28
13	5.69	14.20	80.80	0.33
14	5.88	15.70	92.32	0.34
15	5.84	16.00	93.44	0.41
University students	6.7	20.2	137.0	?



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14	5.88	15.70	92.32	0.34
15	5.84	16.00	93.44	0.41
University students	6.7	20.2	137.0	?

Table 2. Variations of biological and information psychological parameters in adults. Means of various inquiries

Variable (sec)	Coefficient of variation		
	$\bar{x}$	SD	Samples
Short term storage	38.2	4.7	2
Information flow to short term storage	26.4	5.5	4
Information flow to long term memory	25.3	8.8	2
Duration of presence	19.1	2.7	4
Weight of the body or single organs	17.6	9.9	9
Motor capacities	14.5	5.2	11
Physiological functions	11.7	3.3	8
Perceptual capacities	10.9	5.5	2
Metabolic parameters	7.8	3.2	10
Body circumferences at various levels	5.9	0.8	5
Length of the body or the limbs	4.3	0.9	10

and by relatively constant precentages up to the age of 14 or 15 yr. So the average 7-year-old has about 50 to 60% of the capacities (T_R, C_K, C_V) of the 15-year-old.

3.2. *The interindividual variations*

Within the same age group there are individual differences in capacities. A direct representative inquiry is still lacking, but there is an indirect estimate of representative values: the information psychological parameters were measured together with the values in vocabulary intelligence test, which had been standardized on 1952 representative adults of Western Germany in 1974 (Lehrl, 1987). The sample consisted of 672 adults [310 females; age: 42.7 ± 21.1 yr; IQ: 105.6 ± 21.7; r (IQ $- K_K$) = 0.67]. Within the range of 18 to 65 yr no relevant relation with age was noticed. *S*s in the same IQ-intervals of five points (68–72, 73–77, 78–82, 83–87 etc.) were aggregated and their means (medians) in K_K, C_K and T_R calculated. In this way the norms in Table 5 and the regression lines in Fig. 4 resulted. The linear regression of K_K and C_K between IQ 85 and 115 is remarkable. In contrast to this T_R is related to IQ according to a polynome of fourth order (Jeske, Lehrl and Frank, 1982).

As an estimate of the scatter of the information psychological parameters SD was determined for the values which are allocated to the (representative) IQ 115 and IQ 85. The resulting difference was divided by 2. Although this procedure is not correct for T_R it aids the orientation. The results are:

$$K_K: \bar{x} = 80 \text{ bit; SD} = 27 \text{ bit.}$$
$$C_K: \bar{x} = 15.0 \text{ bit/sec; SD} = 3.1 \text{ bit/sec.}$$
$$T_R: \bar{x} = 5.4 \text{ sec; SD} = 0.8 \text{ sec.}$$

It should be kept in mind, however, that even for C_K and K_K outside the range of $\bar{x} \pm 1$ SD the distributions are not normal. This will not be discussed here.

In adults, the individual differences, in basic parameters of information psychology, are more than all of the biological variables, which were investigated by Wechsler (1935), when applying Karl Pearson's coefficient of variation (CV = 100 × mean/SD) for discerning the range in the human species. The capacity of short term storage in adults (Table 2) varies five times more than the brain weight (CV: males = 7.6, females = 8.0). While comparing mental with somatic parameters, Wechsler regretted the lack of units of measurement for the former. Information psychological parameters do not have this drawback (Table 2).

4. THE MEASUREMENTS OF THE BASIC PARAMETERS

The general and differential aspects of the concept of information processing imply the assumptions that the basic parameters (T_R, C_K, C_V):

(1) are unspecific, because the type of information, the sensory modalities and the repertory of signs do not alter the results,
(2) are independent of each other.

We present a brief description of the test procedures after consideration of these two points.

Table 3. C_K of 27 physicians, psychologists and doctoral candidates (age: 26–52 yr; 3 females) of a university clinic reading series of letters or numbers under various conditions

No.	Procedure	Reading	C_K (bit/sec) $\bar{x}$	Number of procedure 1	2	3	4	5
1	20 letters capitals	aloud	22.19	—	ns	ns	ns	ns
2	20 letters small	aloud	23.40	3%	—	ns	ns	ns
3	20 letters small	silently	23.25	6%	5%	—	ns	ns
4	20 letters capitals	silently	22.16	4%	4%	3%	—	ns
5	15 numbers (0–99)	silently	23.40	6%	4%	3%	3%	—

Upper triangular matrix: results of the statistical test according to significant deviation of values of one direction (ns = non-significant, alpha = 0.05; sign-test). Lower triangular matrix: mean percent deviation of the compared capacities (ratio scale level): $100 \times |(C_{K1} - C_{K2})|/C_{K1}$.

4.1. Unspecificity of basic parameters

The prerequisite of information psychological measurement is to determine the information content of the stimuli, and the reactions, and to measure the time between the stimulus and the response. Under certain circumstances the determination of information content, as well as the time, can be simplified. With these prerequisites three basic capacities are recognized as characterizing the individual. These are independent of the kind of sign, be it a letter, a digit, a figure or a chemical symbol. To some extent, they are independent of sensory modalities such as vision and hearing and of the mode of presentation which may be sequential or simultaneous (Lehrl, 1988). On the whole, they are non-specific as will be demonstrated by using the first basic parameter—the information flow to the short term storage.

If a S reads a series of independent letters within the German alphabet of 27 characters at random, his chance of hitting the correct one on the first guess is 1 in 27. To find it along a binary decision tree (Weltner, 1973), the information content is exactly 4.7 bit ($27 = 2^{4.7}$). Because humans can perform only whole binary decisions a letter will contain 5 bit of information. Reading 20 letters of 5 bit each amounts to 100 bit. If a S, like most students, is able to read the following series within 5 sec, it can be stated that he processes information at 20 bit/sec (= 100 bit/20 sec), or 1 bit in 50 msec.

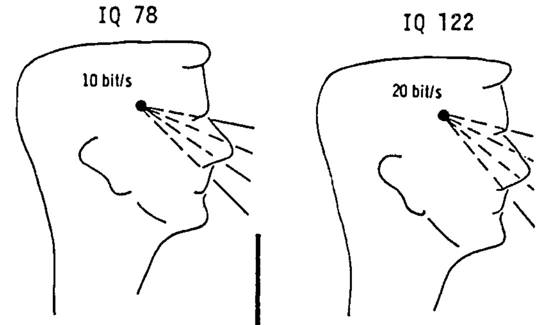
Stimulus:	e h a q g t l v m i b z r u c f p o q d .
Information (bit):	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 = 100.

By experiments it was evident that the time represents recognition and not vocalization, the duration of which is shorter (about 150–200 msec) than that of recognition (250 msec), and which seems to be processed in parallel as soon as a letter is fully recognized (Lehrl, 1988). At this moment already the recognition process of a new sign starts. The time lag of vocalization is compensated when registering the time of reading letters because it occurs as a constant after the first as well as the last letter. Therefore, there is no systematic difference between reading aloud or without overt vocalization (cf. Table 3). Furthermore, the correctness of these conclusions is implied in the results of measurements by means of other signs, which is again demonstrated on the testee who achieved 20 bit/sec in letter reading.

If the same S is asked to read random numbers ranging from 0 to 99 ($100 = 2^{6.7} \rightarrow 6.7$ bit $\cong 7$ bit/number), he will—except for errors of measurement—do it in 3.5 sec with the following 10 numbers. This is because 70 bit/3.5 sec = 20 bit/sec, or 1 bit in 50 msec.

Stimulus:	34 92 15 42 79 83 26 54 18 90 .
Information (bit):	7 7 7 7 7 7 7 7 7 7 = 70.

Completely different stimuli were used by Riedel (1967) and Ehmke (1982). They presented two figures serially on a screen, e.g. the two signs '|' and '<'. When the first appeared the second



			IQ 78		IQ 122
Information psychological measurement of stimuli and reactions	reading letters in 1 s	2	= 10 bit/s	4	= 20 bit/s
	reading numbers (0-99) in 2 s	3	= 10 bit/s	6	= 20 bit/s
	adding digits in 4 s	3	= 10 bit/s	6	= 20 bit/s
	multiplying digits in 3 s	2	= 10 bit/s	4	= 20 bit/s
	stimulus-reaction slope: bits in 100 ms	1	= 10 bit/s	2	= 20 bit/s
	fusion of pictures at Hz		10		20
conventional tests	Standard Progressive Matrices: total score		= 7		= 56
	WAIS: Information: subscore		= 4		= 24
	Culture Fair Intelligence Test: total score		= 12		= 61

Fig. 2. Illustration: the capacity of processing of 10, respectively 20 bits of information/sec is measured by different procedures of the information psychology. But the results in conventional tests are not comparable.

vanished. When the second appeared the first vanished etc. This change speeded up, until the S got the impression of seeing the letter 'K'. The time immediately before the signs fuse is the duration in which just 1 bit of information can be perceived. In praxis it is the mean of changes at the moment of picture fusion in speeding up and picture dividing when slowly down. This occurs at 50 msec in the case quoted above.

According to the information psychological assumption of non-specificity the same student needs 50 msec more in a two-stimuli–one reaction test (2 or 1 bit?), than in a one-stimulus–one-reaction-test (1 or 0 bit?), i.e. 1 bit in 50 msec or 20 bit/sec (cf. Fig. 2). This is concluded from the results of studies, the results of which are presented in Table 4.

There are many problems linked with stimulus-reaction time which can here only be indicated. For the determination of C_K it is necessary to prepare the S for the exact repertory of signs to be expected. He has to remain in the same mode of signs and reactions, e.g. he must not be confronted with acoustic and optic signs, or reactions by hand and feet, but only with acoustic or only with optic signs. Likewise mixtures of repertories are not allowed, e.g. geometrical figures and letters or letters and digits. Strategies have to be excluded. They are facilitated with the increasing number

Table 4. C_K of 16 patients of a rehabilitation clinic (mainly workers; 9 females; age: 48.52 ± 9.48 yr) determined by three procedures

		Correlations (Spearman)	
Procedure	C_K (bit/sec) median	Letter reading	Picture fusion
Double minus simple stimulus reaction time	12.50	0.40	0.69
Reading 20 letters	13.55	—	0.70
Picture fusion	14.00	—	—

of choices and with exercise. Therefore we have restricted our experiments to double-stimulus–one-reaction times and simple-stimulus–one-reaction time. For all that, the amount of processed information is not quite clear. We tend to allocate to the presentation of one stimulus (present–absent) as '*' on a screen already 1 bit. In the double-stimuli mode as 'o' (→ reaction) and 'x' (→ no reaction) there is a second decision containing 1 bit (1. bit: sign is absent or present, 2. bit: the sign for reaction or its alternative). Anyway, the difference between double stimulus and simple stimulus-reaction time corresponds to 1 bit. Our measurements, the results of which are presented in Table 4, were performed by *S*s who had a pretraining with eight simple and eight double stimuli. The actual measurement was under the same conditions. To reduce the well-known high errors of measurement the median was calculated of the five best results under each condition.

All the measurements presented concentrate on time courses of processes of recognition. The information psychological investigations on processes, which are more central or nearer to response, are less detailed. Nevertheless, we have communicated observations on single cases or experiments which were designed for other purposes, but indicating the same results as for recognition, as in selecting random letters on a typewriter or adding or multiplying digits and even scanning from memory (see below, Fig. 3; Lehrl and Fischer, 1988). However, more direct investigations have to be conducted in this field.

Finally, in contrast to the usual psychological measurements, the value of C_K seems to be the same regardless of the modality used: C_K (reading letters) = C_K (reading numbers) = C_K (picture fusion) = C_K (multiple minus single stimulus reaction time) = C_K (adding digits) = C_K (multiplying digits) = $\cdots$.

As one empirical proof the means of C_K determined by different activities are presented in Fig. 3. Still stronger proof is available from the same *S*s when being tested by different procedures for C_K, such as number and letter reading aloud or still and picture fusion, letter reading and multiple minus simple choice reaction time (Table 3 and 4).

Although the procedure of picture fusion (Table 3) implies a slight bias (overestimation because only the values of speeding up the changes were registered) and its reliability, as well as that of

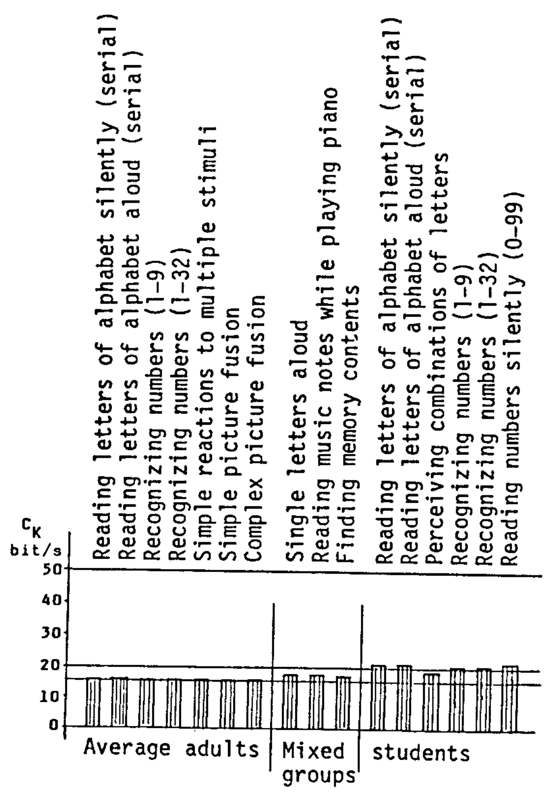


Fig. 3. Average capacities of the speed of information processing (C_K) during different mental activities in different groups. Mixed groups: containing a high percentage of students.

the stimulus-reaction times, is low, the absolute values of C_K within the two investigated samples seem to justify the assumption of non-specificity or generality of C_K.

There are also indications of the non-specificity of the second and the third basic parameters (Lehrl, 1988). The second parameter is the duration of presence which has been described already. Because of its relation with the span of perception, the proof of its non-specificity, as compared to that of the speed of information processing, is more difficult to provide. If the duration of presence is a non-specific parameter, different verbal and numeral procedures performed by the same Ss must give equal absolute values. Therefore the procedures digit forwards (DF), letters forward (LF), syllables forward (SF), independent words forward (WF) are expected to fulfill the equation:

$$T_R(\mathrm{DF}) = T_R(\mathrm{LF}) = T_R(\mathrm{SF}) = T_R(\mathrm{WF}) = \cdots.$$

When the information flow to the short term storage does not exceed the capacity C_K and when the formation of clusters and associations with further knowledge is absent, the equation can be found to apply (Riedel, 1967; Lehrl, 1988). More than 30 publications (Lehrl, 1988) support this assumption. The close relationship of T_R to the span of apprehension remains to be elaborated theoretically. As both basic components C_K and T_R are unspecific, the product K_K must have this feature too. There has been, however, almost no attempt to prove this assumption. The conclusions of seven such investigations conducted by different methods reveals that the expected approximate K_K (bit) is, indeed, achieved (Lehrl, 1988).

The third parameter is the basic speed of learning C_V. It depends on the duration of time between perception and retrieval. The rate decreases logarithmically as the time increases. However, Ss showing a high basic rate after 2 min also tend to score higher after 2 hr or 2 days (Loew, 1938). This confirms the assumption that there is only one basic learning component. If the information content of the material to be memorized is measured, if the forming of associations, organizations and clustering is avoided, and if the time between perception and retrieval is controlled, the assumption of non-specifity seems to hold. Lehrl (1988) investigated the literature according to these criteria and found that the results corresponded only roughly to the above assumption, because the prerequisites in the available studies were not controlled and not compared exactly. But the results hint at a promising way to support the concept of the general or non-specific basic parameters of information processing.

4.2. Independence of basic parameters

Conceptually the three basic parameters of information processing are independent of each other. The measured values, however, often correlate conspicuously. In one investigation on 66 adults, with IQs in the normal range (cf. 5.2), the correlation of the scores of C_K and T_R were as high as $r = 0.65$ (Lehrl, 1988). Some of the correlations can be explained by the process of measurement in which at least two basic parameters are involved. This is understood easily in tasks for the basic learning speed. If nonsense syllables (13 bit/syllable) are presented each per second, then an average adult (C_K = 15 bit/sec) will spend nearly all the time for recognition. A highly gifted student (C_K = 26 bit/sec) has about half a second at his disposal for associations, clusterings or organization of the material.

In short presentation times, if the material is hard to be associated and organized, the advantage of high C_K and T_R seems to decrease (Reimann, 1966; De Groot, 1974; Lehrl, 1988). Because the correlations between C_V on the one hand and T_R and C_K on the other hand tend to be low, particularly under the above mentioned circumstances, the independence of C_V may be maintained. The proof of independence of C_K from T_R is harder, particularly because other authors have postulated the dependence of T_R on C_K (Jensen, 1970; Eysenck, 1986; Weiss, 1986). That conclusion cannot be drawn from the model of psychostructure and there are empirical arguments against the alleged connection:

—C_K increased significantly during the treatment of acute organic psychosyndromes with the nootropic drug 'standardized extract of ginkgo-biloba' while T_R was not influenced (Teigeler and Pieprzyk, 1984).

—During the treatment of presenile dementia with flunarizine, only T_R was increased during the first 6 weeks, while C_K increased 3 weeks later (Lehrl, Sollberg and Schumacher, 1978).

—Wood painters who are chronically exposed to organic solvents have a relatively small T_R compared with controls (Jeske, Lehrl, Schäcke and Lüdersdorf, 1983) while C_K is not affected.

The concept of the independence of the three basic parameters may thus still be maintained.

4.3. Tests for the basic capacities

As has been shown, there are many possible procedures to measure the three basic capacities of information processing. Based on past experience a concrete form has been developed called KAI (Kurztest für allgemeine Intelligenz = short test for general intelligence) which fulfills the usual criteria of practicability, objectivity, reliability and validity. One kind of KAI is administered manually. It has a basic and a parallel form. Each takes 3 to 5 min and determines C_K, T_R and K_K as the product of both. A computerized form of the test, which takes 12 and 15 min, measures the same capacities and additionally C_V. It is conducted by a dialogue between the *S* and the screen of the computer which edits the results. Nine parallel test forms are available in German.

4.3.1. Manual measurement of C_K. It is conducted with a card on which there is a series of 20 independent letters as shown in Section 4.1. The *S* should read these as quickly as possible while the examiner notes the time between the first and last sound of reading (modestly loud). This test is carried out four times. The best time [T(sec)] achieved is counted for determining C_K:

$$C_K = 100\,(\text{bit})/T(\text{sec})(\text{cf. } 4.1.).$$

4.3.2. Manual measurement of T_R. Digits are presented in the same manner as in the well-known test 'digit forward'. Afterwards the same procedure is repeated with letters of the alphabet (letter forward). Since *S*s tend to use clustering from five digits onwards, as has been shown by two investigations (Lehrl, 1988), corrections have to be made in the following manner: 5 digits to 4.7, 5.5 to 4.9, 6.0 to 5.1. From 6.0 digits onwards always subtract 0.9.

The mean of the 'letter forward' and the corrected 'digit forward' is T_R. Because of the combination of letters and digits the differentiation and the reliability increase.

4.3.3. Short term storage K_K. This is calculated by multiplying the results obtained above for C_K and T_R:

$$K_K(\text{bit}) = C_K \times T_R.$$

4.3.4. Measurement of the basic speed of learning C_V. C_V is determined by computer only. To measure this parameter the computer displays 12 meaningless syllables at intervals of 2 sec each, e.g. kov, tek, sil. After a pause lasting 140 sec 36 syllables appear sequentially on the screen. Every time the *S* recognizes a syllable as being one of the 12 previously displayed, he is expected to press the response key. This procedure is then repeated with a different set of syllables. The number of 'correct' responses (R) and that of 'incorrect' ones (f) are recorded. We assume that each syllable has an information value of 13 bit. After the test is completed, an upper limit of C_V is calculated by: $C_V = 13/24 \times ((R) - F/2)$. If this random correction yields a negative value for C_V one can assume $C_V = 0$.

This procedure has still two faults for the measurement of the 'true' C_V:

—It overestimates it. In active reproduction the values are about 1/3 of the results by the above described method of recognition. This may partially depend on the possibility that hints are given in the items which are presented for choice in the procedure of recognition.

—It favours *S*s with high C_V, because they gain time for associations, clusters or organizations.

In future measurements should be made with the syllables adjusted to the individual C_V. That means in case of an normal adult, one syllable per second and a highly-gifted *S* one syllable in 1/2 sec to 2/3 sec.

The procedure of the KAI-test is fixed. Therefore, the requirements of a high degree of objectivity are fulfilled. The reliability coefficients of the manual or computerized measurement in different groups of adults vary between 0.82 (retest of C_V of 1910 persons with diffuse organic brain syndrome) and 0.99 (C_K of 66 roughly representative 'normal' adults). Under most circumstances there will be no systematic effects of repetition (Lehrl, Gallwitz and Blaha, 1980).

Table 5. Norms of adults for the three basic information psychological capacities

Percentile	IQ	Short term storage (bit)	Duration of presence (sec)	Information flow to Short term storage (bit/sec)	Information flow to Long term memory (bit/sec)	Long term memory (bit/sec)	MQ***
99.8	140	179	8.2	25	—	6.34	—
99.7	135	162	7.4	24	—	5.93	—
98.8	130	139	6.8	23	1.14	5.52	130
96.5	125	124	6.4	21	1.09	5.11	125
93.0	120	112	6.1	19	1.05	4.70	120
86.0	115	106	5.9	18	1.00	4.29	115
75.0	110	97	5.7	17	0.96	3.87	110
59.2	105	88	5.5	16	0.91	3.46	105
50.0	100	80	5.4	15	0.86	3.05	100
40.8	95	71	5.2	14	0.81	2.63	95
25.0	90	62	4.8	13	0.76	2.22	90
16.0	85	52	4.3	12	0.72	1.81	85
7.0	80	45	3.7	11	0.69	1.40	80
3.5	75	28	2.9	9	0.64	0.99	75
		K_K	T_R	C_K	C_V^*	C_{VW}^{**}	MQ

*Written recall. Results of De Groot (1974). **Recognition. ***Memory quotient.

The development of KAI is closely related to the basic investigations, which have been discussed above and which support the concept of unspecific and independent parameters of information processing. This is the one aspect of validity of KAI. The second aspect which refers to intelligence will be discussed later.

The adjustment to other languages seems to bring up problems only in the case of letters (in C_K), which have phonetically more than one syllable, because speaking will then last longer than the perception. Carena (1985) solved this problem for Spanish by always adding an 'a': h to ha, f to fa, k to ka etc.

Investigations in Argentina have shown that the distributions of C_K and T_R values are similar to those of Germany (Carena, 1985; Carena, Lespinard, del Solhaune, Ferretti, Pardal, Pliego, Zeta, Fernandez, Tamagno and Rodriguez, 1983). Therefore the norms may be valid in all comparable societies (Table 5).

5. THE CONNECTION OF BASIC PARAMETERS WITH OTHER VARIABLES

We will consider the relations of the basic parameters of information psychology to their biological counterparts and to more complex conventional psychological parameters.

5.1. The biological counterparts

Since the basic parameters are elementary they cannot be divided. Nevertheless, they must have biological counterparts, e.g. the time for the physiological event during which one bit of information will be processed, i.e. the basic period of information processing BIP (msec). For instance, several findings support the assumption that BIP corresponds to a certain interval of latency in visual evoked potentials (VEP). It is expected to start after about 100 msec because simple stimulus-reaction times last about 200 to 250 msec which is to be divided by 2 to consider the afferent and the efferent branch. The results by Ertl (1966) and others (Lehrl, 1980) agree with this supposition. Furthermore, according to these authors the electrophysiological correspondence of BIP may be specified by the distance between the peaks E3 and E2 (P100), because the latency of E3 correlates with IQ, but E2 not. Now the numerical values of (E3 – E2) can be determined at different levels of IQ. Then the same is to be done with BIP. The predictions are that BIP and (E3 – E2) increase when IQ decreases and that BIP and (E3 – E2) agree numerically at different levels of IQ.

The allocation of BIP-length to different levels of IQ must be calculated by means of C_K. That means, for example, that according to the norms (Table 5) for a S with IQ 78 a $C_K = 10$ bit/sec is expected. Then the duration of BIP is $1/10$ sec = 100 msec. If the difference E3 – E2 corresponds to BIP it is expected to amount to 100 msec. The BIP of an average S is 67 msec ($C_K = 15$ bit/sec; BIP = 1/15 sec) and at IQ 122 50 msec ($C_K = 20$ bit/sec). These predictions have been supported relatively well by the individual results of VEP which Ertl and others had published with global IQ (Lehrl, 1980).

Confirmed predictions about the distribution of K_K, according to human-genetic concepts by Weiss (1982), give further hints of a close connection between the information psychological and biological parameters. The same relationship has been indirectly indicated via the connections with intelligence (Weiss, 1984, 1986). But more work needs to be done in this area to show a detailed and stable model of the information psychological and biological relationships.

5.2. The psychological parameters

The basic rate of learning C_V is a non-specific individual value, at a high level of measurement, of the mechanical learning speed which depends not only on the individual's capability but—in contrast to C_V—also on the features of the material to be learned.

C_V is a largely constant value in adults and increases the accumulation of experience almost linearily. Investigations have shown that interindividual differences in C_V do not contribute considerably to the interindividual differences of fluid or crystallized intelligence including vocabulary (Lehrl, 1988). In contrast to this, C_K and T_R are closely related to these parameters of intelligence by concepts as well as by empirical findings. The main reason for this seems to be the connection between C_K and T_R and their product K_K on the one hand, and the chance to detect redundancies in material to be learned on the other hand. This can be a very efficient way of storing a lot of experience or knowledge even though the basic speed of learning is relatively slow. This is demonstrated by the following two lines including patterns which can be learned:

M O E F D F I I C C A E L R
or: 1 2 4 7 11 16 22 29 37.

Ss with relatively quick C_K and/or long T_R can manage more trials to find out the patterns and enhance the chance to simplify the material. So that have to learn MEDICAL OFFICER (mixed: each second word) instead of MOEFDFIICCAELR and 1, this +1, result +2, result +3, . . . to 37 instead of the nine 'chaotic' numbers. The advantages of this method are obvious.

The empirical correlations between C_K and T_R and its product K_K with global intelligence scores, as shown by several authors and summarized by Lehrl (1988), could serve as proofs for this relationship with intelligence. The most extensive investigation on adults ($N = 672$; cf. 3.2) has shown the correlation ($r = 0.67$) between the capacity of short term storage K_K (bit) and the results of a vocabulary test often tried as an intelligence test (Fig. 4). In another study in 66 adults (psychiatrically normal; age: 39.28 ± 16.13 yr; IQ: 99.30 ± 16.06) K_K correlated with the same intelligence test ($r = 0.80$; Lehrl, 1988).

Because the connections are linear in the interval from IQ 85 to IQ 115, Jeske *et al.* (1982) suggested the following rule of thumb for the quick determination of IQ: $\text{IQ} = 0.56 \times K_K(\text{bit}) + 55$. The concepts of C_K and T_R are closely related to more usual concepts of psychology of intelligence which developed separately. C_K is connected with speed of information processing and T_R with primary memory, immediate memory, short term storage etc.

This is shown by the same tests which are based on the information psychological hypothesis as well as the traditional intelligence concepts e.g. digits forwards.

Almost 'pure' tests or subtests for C_K, but without consideration of the information contents of stimuli and responses, are the 'digit symbol' in WISC or WAIS or the Reitan trail making test which was applied as an intelligence test by Oswald and Roth (1978). The inspection time technique (Lally and Nettelbeck, 1977; Brand, 1984; Egan, 1986), card sorting (Oswald, 1971) and the slope of stimulus-reaction times (Hick, 1952; Roth, 1964; Spiegel and Bryant, 1978; Jensen, Schafer and Crinella, 1982) are still closer to C_K, though these authors failed to connect the time spent in processing 1 bit with the IQ.

T_R is within the traditional concepts of the relationship between immediate memory (short term storage; span of apprehension etc.) and intelligence as measured by digit forward, letters forward, syllables forward etc., as contained in the intelligence test by Binet–Simon or in the WISC and WAIS by Wechsler. Fundamental theoretical and empirical work in this area has been carried out

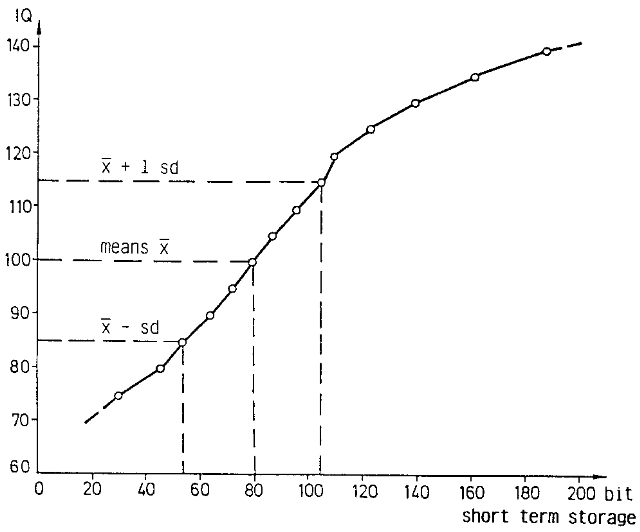


Fig. 4. Relationship between the capacity of short term storage K_K and global intelligence quotient (IQ).

by Süllwold (1964), Melton (1967), Whimbey, Fischhoff and Silikowitz (1969), Jensen (1970), De Groot (1974), Lyon (1977) and others.

Since C_K and T_R correlate moderately, there are practical reasons, especially the saving of time, for measuring only one of these for the determination of IQ. But various factor analytic studies by independent investigators of intelligence agree that two factors need to be considered, which should relate to speed of information processing and immediate memory (or span of apprehension): Horn (1968); Das, Kirby and Jarman (1975); Brown and Kirsner (1980); Oswald and Fleischmann (1986).

These factor analytic findings, although they do not necessarily include both the components, support the suggestion to do so, especially since their measurement is not very time-consuming (cf. Section 4.3). The notion of creativity proposed by Ruth and Birren (1985) likewise implies two of three components (speed of information processing; complexity of information processed; willingness to risk new solutions to possible problems in the given information). The first two contain the concepts of C_K and T_R as was shown by Fischer and Lehrl (1986).

C_K and T_R are parameters which characterize the individual by a non-specific and fundamental value and not by the type of tasks as conventional intelligence tests do. In contrast to IQ, C_K, T_R and K_K are measured at the level of a ratio scale because a unit of measurement and an absolute point of zero are given. Although these scores are individual they can be related to reference groups and even to IQ.

It has to be admitted that some additional important aspects of IQ such as capability of persistence and control of activity, as claimed by Eysenck (1982, 1986), are not covered. Also missing are the flexibility of shifting from one repertory of signs to another (which is allocated mainly to the accommodator) and strategic processing [about which some information psychological investigations are available (e.g. De Groot, 1974)]. However, information psychology provides the possibility to reconstruct and substitute these values for the confused concepts of intelligence (Langeveld, 1967).

Finally the information psychological concepts of intelligence provide practical benefits which are similar to those of intelligence tests, particularly those for fluid intelligence. They predict the achievement and orientation in everyday life, as shown by Whimbey and Ryan (1969) and Oswald (1981), and social success (Eysenck, 1979). The basic parameters of information psychology are reduced by cerebrovascular and cerebral metabolic diseases (Blaha, 1980). Therefore the measurement of K_K—and C_V—is used in various studies to assess the therapeutic effect of nootropic drugs, such as piracetam or vincamine (Böhlau, Pelka and Schildwächter, 1984; Blaha, 1984; Steinhäuser, 1985; Fischer, Weidenhammer and Lehrl, 1986; Bartels, 1986) and the effect of mental exercises, e.g. 'brain-jogging' (Glowacki, 1986; Weidenhammer, Glowacki and Grässel, 1986) which is based on the fundamentals of information psychology.

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