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The Structure of Vigilance

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Summary. Vigilance is understood as a primarily behavioral category. Identical stimuli tend to evoke more or less differentiated behavioral responses dependent on a low or high state of vigilance. The rise of vigilance from coma to full attention moves along with increasing differentiation of evoked behavioral responses. With heterogeneous physical, figurative, and verbal stimuli, responses are elicited which can be arranged on an additive (Guttman) scale. Thus, vigilance is suggested to represent a one-dimensional function of the brain.

Key words: Attention – Coma – Guttman scale – Vigilance.

Everyone knows what attention is. So said William James and so began Chapter II of his book, *The Principles of Psychology*. But does everyone know? Nowadays people are less optimistic concerning this issue [14][1].

First of all, attention is not an homogeneous phenomenon. According to Berlyne [2] one distinguishes selective and intensive aspects of attention.

Whereas selectivity plays a major role in all models of attention, people usually underestimate the importance of the intensive aspects in a theory of attention. These intensive phenomena are described by various ill defined terms such as 'attentiveness,' 'wakefulness,' 'alertness,' and 'activation.' 'Arousal' and 'vigilance' are considered to belong to the same class.

For phenomenological reasons 'vigilance' seems to be an appropriate term, introduced by Head [8] in 1926. In his understanding, 'vigilance' is primarily a behavioral category. The main point is not diminution or increase in the strength of stimulus which is required to evoke a reaction, but the *fundamentally divergent nature* of the behavioral reactions depending on whether the organism is in a high or low state of vigilance. Identical stimuli tend to evoke a more complex reaction during a high than during a low state of vigilance.

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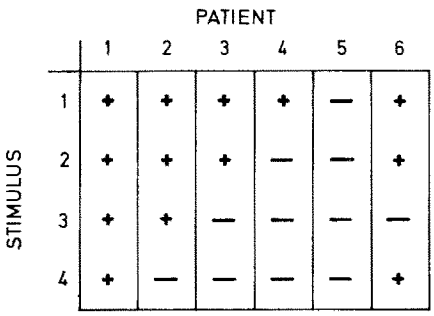


Fig. 1. Model of a Guttman scale. Behavioral reactions of 6 patients to different stimuli

The literature provides a rich set of data about the electroencephalographic patterns correlated with vigilance [6, 11, 15—17, 19]. But fewer data are available on the behavioral features of the different stages of vigilance in man. All of them refer to comatose states [6, 9, 18]. So far there has been no attempt to investigate the *behavioral* correlates of vigilance between coma and the states of unrestricted attention.

The first problem is to find tests which are able to elicit reliable behavioral reactions in comatose patients as well as in subjects with only slightly impaired vigilance.

In order to elicit reactions in comatose patients strong and *non-verbal* stimuli must be used. The assessment of these low levels of vigilance is based on the observation of *involuntary* behavioral reactions. On the other hand, patients with slight diminution of vigilance can be distinguished only by their *voluntary* performances in more complex and *verbally* mediated tests.

These different strategies for measuring vigilance are justified only if the increase of vigilance along the continuum from coma to full attention is responsible for the growing complexity of evocable behavioral reactions. That means, in other words, the availability of any brain function depends on the integrity of specific neuronal structures, but presumes as well a definite amount of vigilance mediated by highly unspecific, for instance monoamine, brain mechanisms [13].

It is the aim of this paper to demonstrate the relationship between level of vigilance and the corresponding complexity of behavior.

If one succeeded in arranging the elicited behavioral reactions on an additive scale [7], their suggested hierarchical order would become plausible.

Figure 1 shows the principle of an additive or Guttman scale. The responses of one patient to four stimuli ($S_1 \ldots S_4$) are represented by a column of plus and/or minus symbols. Plus means response, minus no response. According to the concept of additivity, the reaction to a stimulus of less behavioral efficacy presumes the reaction to the foregoing stimulus (stimuli) with higher efficacy. Patient No. 6, for instance, is suggested to react to Stimulus 4 without a response to Stimulus 3. Thus, this patient makes an error on the additive scale.

The *Munich Coma Scale* (MCS) is a Guttman scale suited for the assessment of level of coma. The MCS consists of two additive sub-scales, (1) the scale of *susceptibility to stimulation* and (2) the scale of *reactivity*.

Table 1. Munich Coma Scale/Scale of susceptibility to stimulation

Stimulus	Definition
Electrical	Battery-operated device for electric shocks. Intensity of current 1—10 mA due to the actual skin-resistance. Minimal voltage 600 V. Plain electrodes at the extensor side of the index and middle finger, in case of sensory impairment in both hands at the lobe of the ear. Stimulation until reactions occur, up to 5 s maximum
Tactile	2 cm flexible nylon-hair, 0.05 mm in diameter. Stimulation of the para- and intranasal as well as the perioral region on both sides of the face for at least 30 s
Acoustic	Siren. Battery-operated device. Sound pressure level 90 dB. Frequency range 300—1000 cps. Stimulation of both ears for at least 30 s
Optical	Focused flashlight. Light intensity 4000 Lux. Flashing the light (ca. 1 cps) in both eyes for at least 30 s

Table 2. Munich Coma Scale/Scale of reactivity

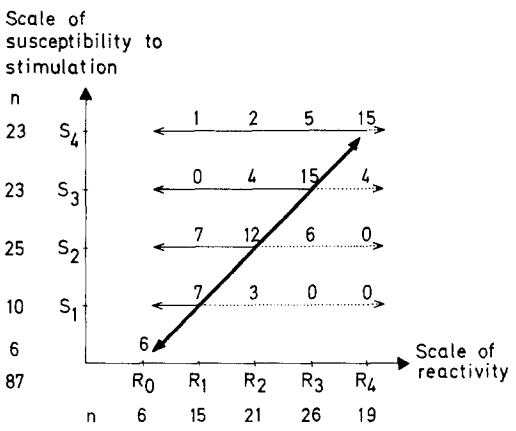
Type of reaction	Definition
1	Any movements of the body, movements of the head *without clear-cut* directional components in relation to stimulus or experimenter
2	Any oro-facial (mimic) movements, e.g. frowning, single or repeated contraction of eyelids with closed or open eyes, any movements of perioral muscles, of tongue or of muscles involved in the act of swallowing
3	According to direction and duration *unequivocal* turning of the head to or away from stimulus. Opening of eyes or state of open eyes
4	According to direction and duration *unequivocal* looking at stimulus or experimenter. Verbal utterance of evident semantic content.

The first scale is based on four physical stimuli: one electrical (E), one tactile (T), one acoustic (A), one optical (O). The specifications of the stimuli used are indicated in Table 1.

Only overall reactions to each stimulus are measured, and the four stimuli are ordered according to their power to elicit any reactions, the order being stimulus E more powerful than T, T more powerful than A, A more powerful than O. Thus the scale has five steps, four of which correspond to the ranked stimuli, the fifth being 'no response.'

The scale of reactivity consists of four classes of behavioral responses (Table 2). Each class includes several distinct reactions. The first class includes general motor reactions, the second any oro-facial (mimic) reactions, the third orienting, and the fourth communicative reactions.

By combining single responses to four classes of reactions the interindividual variance could be reduced and an additive scale obtained. The classes of reactions are ranked according to their occurrence at different levels of coma, the order being motor before oro-facial before orienting before communicative reactions.



MCS-S = MCS-R	49 (60%)
MCS-S > MCS-R	19 (22%)
MCS-S < MCS-R	13 (16%)

Fig. 2. Relationship between the scale of susceptibility to stimulation and the scale of reactivity in 87 patients with disturbances of consciousness

The scale of reactivity also has five steps, four of which correspond to the four classes of reactions, the fifth being 'unresponsiveness.'

Both scales are in a certain manner independent of each other. The scale of susceptibility to stimulation was developed by pooling the four classes of reactions. For the scale of reactivity on the other hand the stimuli were pooled.

Errors of additivity are below 3% for both scales in about 400 patients hitherto examined. According to Guttman himself a reliable additive scale is allowed a 10% error. Repeated errors indicate a bilateral lesion in the respective sensory modality.

The two scales do not measure the same variable. The scale of susceptibility to stimulation allows the assessment of *behavioral arousal* and the scale of reactivity indicates lowgrade *vigilance* according to the above definition of vigilance.

The combination of both scales results in a matrix (Fig. 2).

Each patient is given a distinct position in that matrix according to the step he reached on the two additive scales of the MCS. The majority of patients fall along the main diagonal, indicating a high correlation (about 0.80) between behavioral arousal and vigilance in a great number of comatose states. Eight patients, however, reached a high level of behavioral arousal, in so far as they reacted to all four stimuli, combined with a lower grade of vigilance; they attained only Step 1, 2, or 3 on the scale of reactivity. Among these patients are six who suffered a so-called *apallic syndrome*. On the other hand, there are patients with the inverse pattern, which is often observed in the course of cerebral intoxication.

Nevertheless, patients may be somnolent or drowsy by clinical criteria without any deficit in the coma scale. Slightly impaired vigilance cannot be detected by these crude physical stimuli. Weaker stimuli, however, which still elicit reliable behavioral reactions, can hardly be found. The measurement of finer deficits of vigilance requires test material of higher complexity. Heterogeneous tasks are necessary to prevent a complete failure of the measuring instrument by a deficit of

Table 3. Guttman-scale of high-grade vigilance

Step of scale	The patient is requested
0	To shut his eyes
1	To shake hands
2	To tell the place of residence
3	To tell his age
4	To combine 3 out of 4 Elizur blocks
5	To solve a task of interference
6	To accomplish 6 out of 10 tasks of the Benton-test, form C
7	To reproduce 3 out of 4 Elizur drawings

Test instructions are either given verbally or in written form

one specific brain function. Furthermore, the tasks must consider, as far as possible, the different motor capacities the patients have on different levels.

The applied tasks are shown in Table 3.

Task 0 corresponds to Step 4 on the MCS scale of reactivity. Patients with communicative reactions were found to be able to shut their eyes at verbal or written command.

In Task 1 patients must shake hands at command [12]. Tasks 2 and 3 test basic temporo-spatial orientation; patients are requested to tell their place of residence and their age. On the next step the ability to perceive and analyze forms is examined; four dichromatic geometrical patterns must be copied successively using four polychromatic Kohs-blocks. It is a modification of the test which Elizur [4] developed for the diagnosis of organic brain conditions. Three correct solutions out of four are demanded to reach criterion. The following task uses interfering verbal material. There are two lines with the letters A and B in random order; patients must spell B for A and vice versa. Only two mistakes are accepted in a string of 17 letters. In the next task the patient must detect a previously shown geometrical figure in a diagram containing four similar figures. The patient has to find the solution in at least six out of 10 diagram with increasing difficulty. In this way Benton and Spreen [1] tested visual memory, avoiding as much as possible verbal and motor performances. Finally the patient is requested to draw four successively shown geometrical figures from memory. The patient must be able to analyze forms and to reproduce them from memory. To pass this test three drawings out of four must be correct. This task is also taken from Elizur's test. It must be emphasized that all tests are given without any time limit. This procedure as well as the definition of cutoff points helps considerably to reduce inter-individual variance. However, further experience is needed to decide properly if the applied cutting points are useful or not.

The described tasks were selected out of eleven different classes of tests with several subtasks by a scale analysis, a procedure indicated by Goodenough [5]. The eight tasks described above fitted best into a Guttman scale. Of the 120 patients hitherto tested, 16 made errors on that scale, and among them 12 missed

only one of the additive steps. An analysis of the errors showed that they seem to result from incidental fluctuations without systematic interference of any additional factor. Some errors may be due to a motivational factor while others reflect memory or language disturbances. A specific functional deficit becomes evident if in repeated measurements the same task is always missed.

A mean correlation (0.54) was found between the achieved test result and verbal intelligence assessed by a standardized multiple vocabulary test, the MWT-B [10]. With regard to age a distinction can be made only on the topmost step of the scale. Patients older than 50 years performed worse than younger ones only in Task 8. As for the validity of the scale, all patients with a disturbance of vigilance, claimed by clinicians, showed distinguishable deficits on the scale. On the other hand, 50 neurological patients without any clinically evident disturbance of vigilance reached at least the next to the last step of the scale.

In conclusion, the rise of vigilance from coma to full attention moves along with increasing differentiation of the elicited behavioral responses. In spite of increasing interindividual variance from coma to full attention, the suggestion of a continuous dimension of vigilance as a fundamental aspect of attention seems to be reasonable.

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