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Prevention of excessive mental load, and how can the industrial engineer and the ergonomist co-operate.

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Several considerations form the basis of this paper.

The first is that the application of ergonomics to practice generally does not go further than optimizing such parameters as the height of tables and chairs, reaching distances, the placement of knobs and dials, etc., and even on these points existing ergonomical knowledge is not always applied.

One of the main reasons for this limited outlook could be that ergonomists often feel satisfied playing the role of missionaries, preaching what has to be applied but leaving the translation of good advice into hardware to the engineer.

In contemporary machine and tool design, engineers are more and more utilizing ergonomical principles and expertise. In designing man-machine systems, however, the ergonomics of the man-machine interface includes not only considerations related to the correct placement of knobs and dials but also the procedure set down for the particular system. Mental work load resulting from information handling depends essentially on this procedure.

Engineers, in their traditional role, choose between different existing alternatives, comparing pro's and con's with regard to such criteria as output, cost, reliability, etc. In practice, only a few engineers have the expertise and the time to translate new principles into hardware. Even fewer engineers have the expertise, time, and the interest to apply such principles as human factors which do not traditionally belong to the field of engineering.

I believe the ergonomist is wrong by thinking that his work is limited only to the developmeht of new principles and norms. Ergonomical research has to go a step further to deliver as a product alternatives which meet the same standards as the existing

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production methods and procedures of information processing, and which simultaneously satisfy human factors criteria.

The development of these alternative methods and procedures must be undertaken by an interdisciplinary group comprised of engineers, psychologists and physicians as is traditionally the case in ergonomical research. The work of this group, however, starts where the traditional ergonomical research ended. Its product consists of carefully designed alternative systems which meet both human factors criteria as well as the traditional technical and economical criteria.

The second consideration is as follows. One of the principles which has become fashionable recently is job enrichment. This, however, is only a principle. One could ask to what extent jobs can be enriched without creating excessive mental load. Proposals of job enrichment have to be checked with regard to their mental workload. The ergonomist must not feel satisfied just because jobs are enlarged but must be in a position to specify whether a certain sequence of subtasks does not overload or underload the workers.

The third and perhaps most important consideration is how to avoid excessive mental overload as well as excessive underload in future systems. This could be called Preventive Ergonomics

The rapid development of the systems approach in designing new systems makes it necessary to take into account the problem of mental load at an early stage of the planning phase. This is due to the fact that mental workload, as already mentioned, depends largely on the procedure set down for the particular system.

For instance: production methods including conveyor belts create problems of mental underload; group production creates not only problems of psycho-social order but also implies that each worker encounters more tools and parts, giving rise to problems of decision.

Excessive mental underload as well as overload can have detrimental effects on health and performance. These effects can endanger the overall aims of the system and can increase absenteeism. Excessive mental load can also change the state of mind of the workers, making them more sensitive to feelings of social dissatisfaction which otherwise could have been tolerated. All these effects are becoming increasingly costly. The question of how to avoid excessive mental load therefore becomes a necessity not only from the humanitarian point of view but also in terms of economics.

Mental workload really means the load for the central nervous system created by performing a particular task. Excessive mental workload means that the central nervous system cannot cope with the processing of the information associated with the task. The central nervous system is not a computer especially conceived to perform industrial tasks. The internal organisation of the nervous system has evolved in the biological struggle of survival, adapting itself to a biological environment and, indeed, trying to adapt this environment to its needs. For these reasons the functioning of the central nervous system has characteristics and limitations which are sometimes unpredictable and cannot be changed. These characteristics and limitations are not obvious and have to be elucidated by scientific means.

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The central nervous system is never truly at rest. There are two main states of functioning: sleep and wakefulness. The state of wakefulness implies a certain intensity of functioning. This intensity of functioning depends mainly on the flow of information passing through the nervous system. An actual flow of information is not only composed of the information to be handled during task performance but also by spontaneously generated information such as worries, plans, desires, etc., and by the information coming from a broader context of work: conversation with co-workers, signals belonging to other tasks, and various other forms of distraction.

Only when an individual nervous system is functioning between certain limits of intensity does a feeling of well-being persist. If these limits are exceeded for more than some period of time, unpleasant feelings are experienced. An excess in the direction of overload requires a period of recovery. An excess in the direction of underload can create boredom but can also provide recovery from an overload.

The key question in the prevention of excessive mental load is how to deduce the necessary level of activity of an individual nervous system from a given flow of information. There is no direct correlation between these two. Depending on the level of training and experience, a flow of information can be handled as a routine constituing a low level of mental load. However, prior to experience, the handling of the same amount of information implied a heavy load for the same individual central nervous system.

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Human behaviour is prepared by the central nervous system, which could therefore be called the "kitchen" of our controlled behaviour. For example, the activity needed to serve certain vegetables could range from opening a tin and cooking them to going to the cellar or to the market place and buying them. But when these vegetables are on the daily menu they will be ready to be served at any given moment. Thus it is not possible to deduce from the presence of vegetables on the table the activity that put them there.

Further, in order to be able to deduce levels of activity from intensities of information flow, both have to be expressed in comparable units. For that purpose, behaviour can be described as the realization of programmed series of action patterns.

An individual central nervous system has at any time a stock of action programs at its disposal. However, at a given moment in the work situation only a few or even one program would fit the momentary situation. This means that programs and subprograms must be selected. The selection of a subprogram requires a moment of conscious attention. With experience, sequences of subprograms become a fixed program. Within such a fixed program, moments of conscious attention are no longer required unless something unexpected happens. Therefore, for a given task, the number of moments of conscious attention decrease as a function of experience.

In a binary choice task in which the stimuli that have to answered are randomly presented, the response to each stimulus requires a moment of conscious control. In dual task situations using a binary choice task as distraction, it has been shown that there is only a limited number of moments of conscious attention per minute available to control our behaviour. For normal persons, the maximum number of moments per minute varies between 60-80 on average. With 60-80 ch/min., the attention capacity is fully occupied, as is shown in Slide 1. This maximum, however, can only be maintained for about 3 minutes and is lower for greater endurance times as can be seen in Slide 2.

Thus the binary choice task allows us to quantify the attention capacity as the number of moments of conscious control per minute.

Based on this third consideration we propose to estimate mental workload in terms of the number of moments of conscious control per minute required in industrial tasks.

With <u>existing tasks</u> this could be done by a sequential analysis of the actions required by the task, e.g., by a flow diagram. From this diagram one would attempt to identify clusters of actions which constitute fixed routine programs, count the number of such clusters occurring per minute, and add to this figure the number of unexpected events in the same period.

During the <u>planning phase</u> of systems, tasks are not defined sufficiently to apply this method. Moreover, during the planning phase, different propositions about the procedure set down for the system have to be compared to reject procedures which would give rise to tasks with a very high or a very low number of moments of conscious control per minute. Fortuitously, we discovered that it is also possible to estimate the number of these moments by observing the man at work. For this purpose a six point scale was used, as can be seen in Slides 3, 4 and 5.

In the upper two categories, corresponding to the maximum attention workload, no moments of conscious control are left for things other than the task. The worker's attention is entirely absorbed by his work. In category VI there is an additional factor which could be called "work pressure". Even the right man can only perform this task when highly motivated. In category V the worker's attention is again entirely absorbed by his work, but no special motivation is required.

The estimates are always made in practice by observing actual individuals performing tasks in a given environment. Of course, more general assumptions based on such estimates in practice have to be carefully checked in controlled laboratory experiments. The estimates are made per minute and noted on a sheet representing a detailed description of the sequence of subtasks comprising the job.

Category IV and III represent normal attention workload. In category IV, although frequent conscious attention is required by the task, there are moments free to communicate with co-workers, to look around, or to devote attention to preoccupations. These moments cannot freely be chosen but depend on the performance. In category III, the opposite is true; although there are frequent moments of conscious control available to pay attention to other things, at special moments, depending on the performance, the task requires complete attention. Category II and I represent underloading. The task does not occupy enough moments of conscious control to keep up the required level of mental activity to maintain the desired level of wakefulness.

As said before, the attention workload is estimated per minute. If within a minute Category IV and I appear alternatively, this period can be designated as I/IV. The attention workload is measured by estimating the number of moments of conscious control left by the task, and hence the task load is measured indirectly. The task load itself can be expressed in percentages of maximum attention capacity:

Category VI represents a loading of 75-100%;

Category V, 50-75%;

Category IV, the upper part of 25-50%;

Category III, the lower part of 25-50%;

similarly for Category I and II for loading below 25%.

As the estimates are made in practice, the 100% refers to an individual maximum attention capacity if the attention workload of one worker is measured. If the load of a group of workers is measured, 100% refers to the group-average maximum capacity. As previously mentioned, the attention capacity is supposed to be measured by the number of binary choices a man can answer without errors (or with a tolerance of one or two errors per minute) for a given endurance time. Therefore the percentage scale of the previous slide can be replaced by binary choices per minute, as shown in slide 5. Referring to what is known from experiments with binary choices, the Categories VI to I can be scaled by psychological and neurophysiological criteria as follows:

Category VI corresponds to a binary choice task with frequencies between 60-80 choices per minute. Moreover, one knows that this represents a man's reserve capacity which will only be used when he is highly motivated. However, if reserves are depleted there will be a mental collapse or a cardiac attack. Therefore, working in this category represents a danger to health. Category V is only acceptable for a limited working time for the reason that human attention is normally fluctuating and if it has to be used continuously for long durations, overload will result. Category II and I underload the central nervous system, but they can be used for recovery from foregoing heavy attention workloads. If they represent the whole work shift, boredom will inevitably occur.

In this way it seems possible to realise a categorization of all kinds of tasks, corresponding to the number of moments of conscious control per minute that they require.

Existing production systems could be compared by means of group average time spent working in various categories, as shown in Slide 6 and 7. Slide 6 shows the combined results of group working time spent per attention category. The solid line represents a work with marked tendency to produce mental underload. The dotted line shows what is expected by applying this form of job enrichment. A third line could be added representing the actually measured group working time spent per attention category after job enrichment. Slide 7 shows an individual working profile characterized by infrequent peakloads. The right man to cope with the peakload will spend most of his working time underloaded. The dotted line represents a profile which could give satisfactory work for a man with an average attention capacity.

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In neurophysiological studies it has been shown that tasks requiring a high number of moments of conscious control per minute - even of short duration - require a long recovery time. One of the sources of mental fatigue and of deterioration of performance is probably due to the accumulating effects of tasks to which insufficient recovery time was allotted. Previously it was mentioned that subtasks with very low workload level could function as recovery periods. Defining necessary recovery periods leads to a sequential analysis of the effects of subtasks of certain duration. Such an analysis makes it possible to specify ideal sequences of subtasks, e.g., tasks of Category VI performed for ten minutes must be followed by tasks of Category I or II for at least three minutes, or by tasks of Category III/IV for at least 15 minutes. With this type of sequence, mental fatigue caused by accumulating effects of insufficient recovery will not likely be found, even for existing shift durations. Slides 8 and 9 give hypothetical examples of correct and incorrect task sequencing. Slide 8 shows an individual attention curve during work. After a working period in a category characterized by overloading, a period in Category II follows. On its own this is a correct sequence. However, the working period in Category II is too short to allow sufficient recovery and the effect of accumulated workload is carried over into the next period of high attention. This period is followed by work of Category II but again of too short duration to provide necessary recovery. Therefore a high effort is required for a subsequent normal attention period. The peakload which follows directly requires.

a high level of motivation but at the same time, because of an increase of the risk of inattentive moments, the performance will suffer. Slide 9 represents a correct individual attention curve during work. Therefore performance requires normal attention activity and will not require special effort. A following high level of attention workload could then be experienced as "stimulating".

In applying job enrichment techniques, the sequence of subtasks is nonetheless specified by the production process. However, with this new method, task sequence proposals can be put forward in terms of attention categories. Since there are many alternative forms of subtasks which fit a particular category, the proposed sequence is actually very flexible. This makes it possible to mutually optimise task suitability and production criteria.

In conclusion, I hope this method of task analysis will form a realistic basis for Preventive Ergonomics.

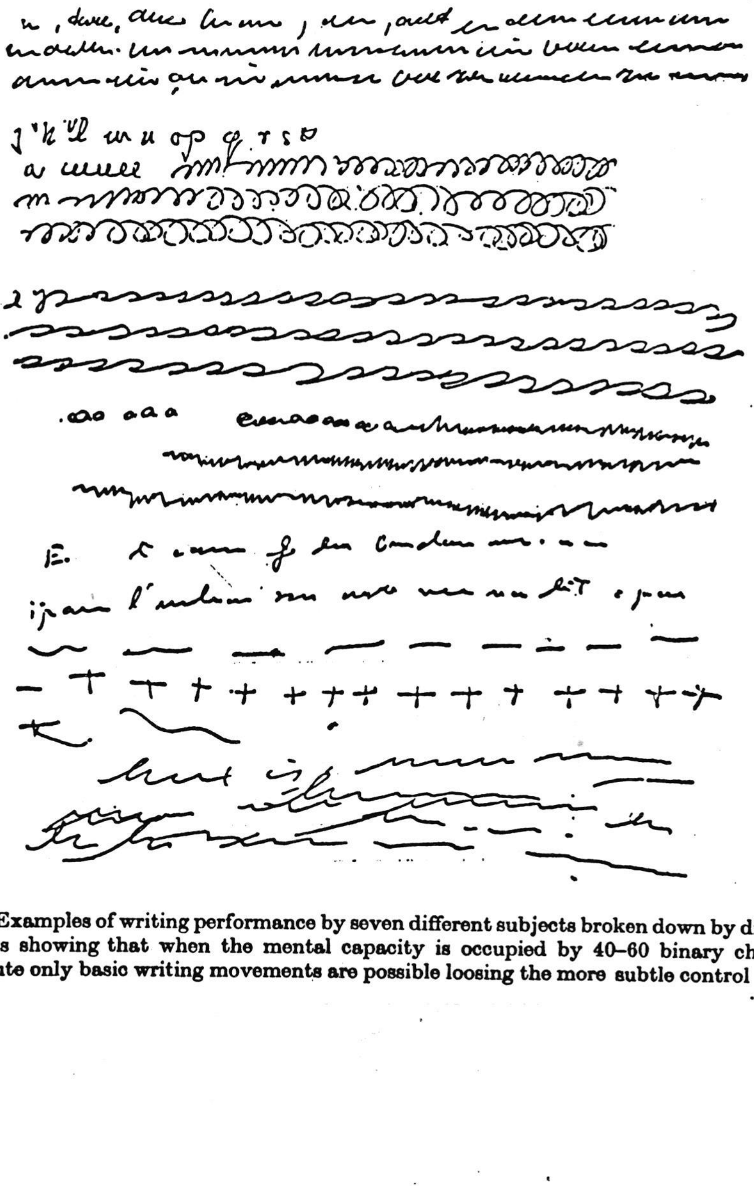

Figure 1 . Examples of writing performance by seven different subjects broken down by distraction stress showing that when the mental capacity is occupied by 40–60 binary choices per minute only basic writing movements are possible loosing the more subtle control faculties.

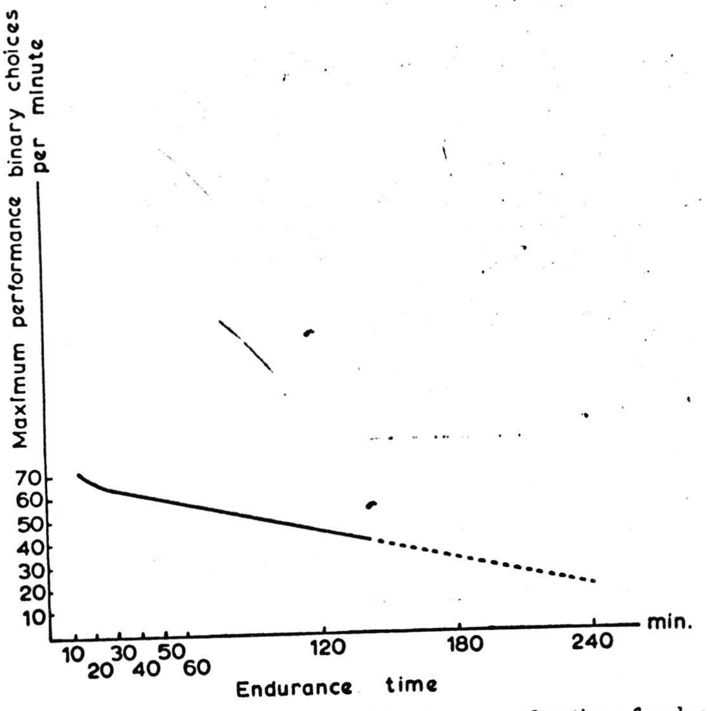

Figure 2. Maximum performance in a binary choice task as a function of endurance time in paced condition with an error tolerance of three errors during three consecutive minutes.

ATTENTION CATEGORIES	
VI USING RESERVE CAPACITY (DANGER FOR HEALTH)	INFORMATION HANDLING WORKLOAD UNDER PRESSURE, NO MOMENTS OF ATTENTION FREE TO HANDLE INFORMATION OTHER THAN FROM THE ACTUAL TASK. EXAMPLE: PEAKLOAD IN AIR TRAFFIC CONTROL. DRIVING AN AMBULANCE IN HIGH TRAFFIC. HIGH MOTIVATION REQUIRED.
V OVERLOAD IF LONG ENDURANCE TIME	HIGH INFORMATION HANDLING WORKLOAD. TASKS ASKING FOR CONTINUOUS CONTROL. NO MOMENTS OF ATTENTION FREE TO HANDLE INFORMATION OTHER THAN FROM THE ACTUAL TASK, BUT NO SPECIAL MOTIVATION IS REQUIRED. EXAMPLE: DIFFICULT POSITIONING TASKS. DRIVING IN HIGH TRAFFIC.
IV NORMAL LEVEL OF MENTAL ACTIVITY	THIS REQUIRES FREQUENT CONSCIOUS ATTENTION. MOMENTS FREE TO HANDLE INFORMATION OTHER THAN FROM THE ACTUAL TASK E.G. CONTACT WITH OTHER WORKERS, LOOKING AROUND, TIME FOR HIS OWN PERSONAL PREOCCUPATIONS (THIS ONLY COULD BE DONE AT SPECIAL MOMENTS DEPENDING ON THE PERFORMANCE). EXAMPLE: PUTTING NUTS AND BOLTS TOGETHER WHICH DO NOT PROPERLY FIT.
III NORMAL LEVEL OF MENTAL ACTIVITY	TASKS PERMITTING QUITE FREQUENT ATTENTION TO INFORMATION OTHER THAN THE ACTUAL TASK. BUT AT SPECIAL MOMENTS TASK PERFORMANCE REQUIRES COMPLETE ATTENTION. EXAMPLE: CAREFULLY CARRYING A GLASS TUBE ON SHOULDERS.
II I UNDERLOADING	ATTENTION IS REQUIRED ONLY INCIDENTALLY. TASKS COMPRISED OF SUB-ROUTINES WITHOUT INCIDENTS. REPETITIVE WORK WITHOUT TARGETTING PROBLEMS. TASKS REQUIRING ONLY SUPERFICIAL ATTENTION, ROUTINE WORK.

FIGURE 3.

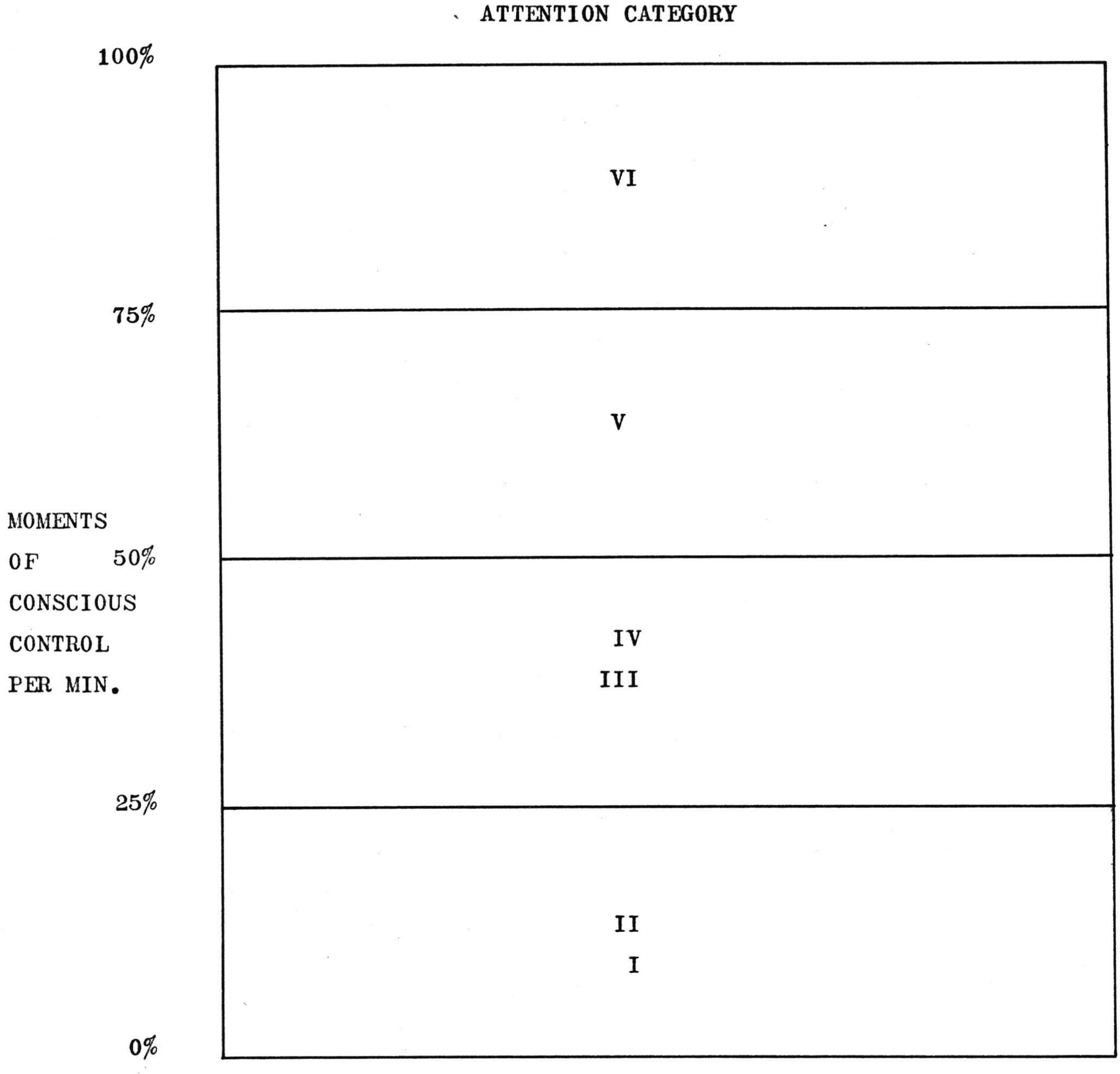

FIGURE 4. CATEGORIES OF ATTENTION AS A PERCENTAGE OF MAXIMUM ATTENTION CAPACITY.

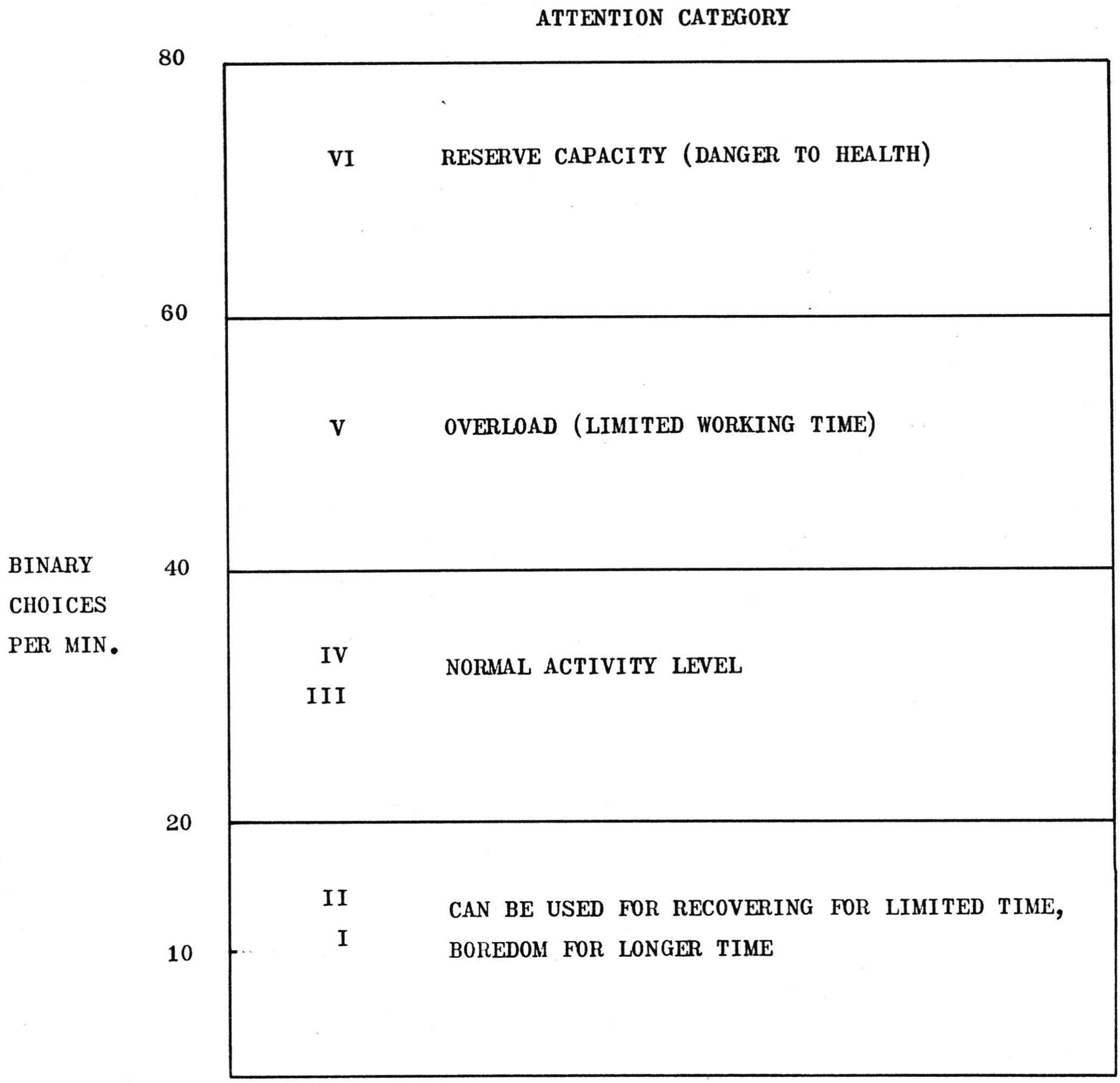

FIGURE 5. CATEGORIES OF ATTENTION IN TERMS OF BINARY CHOICES HANDLED PER MINUTE.

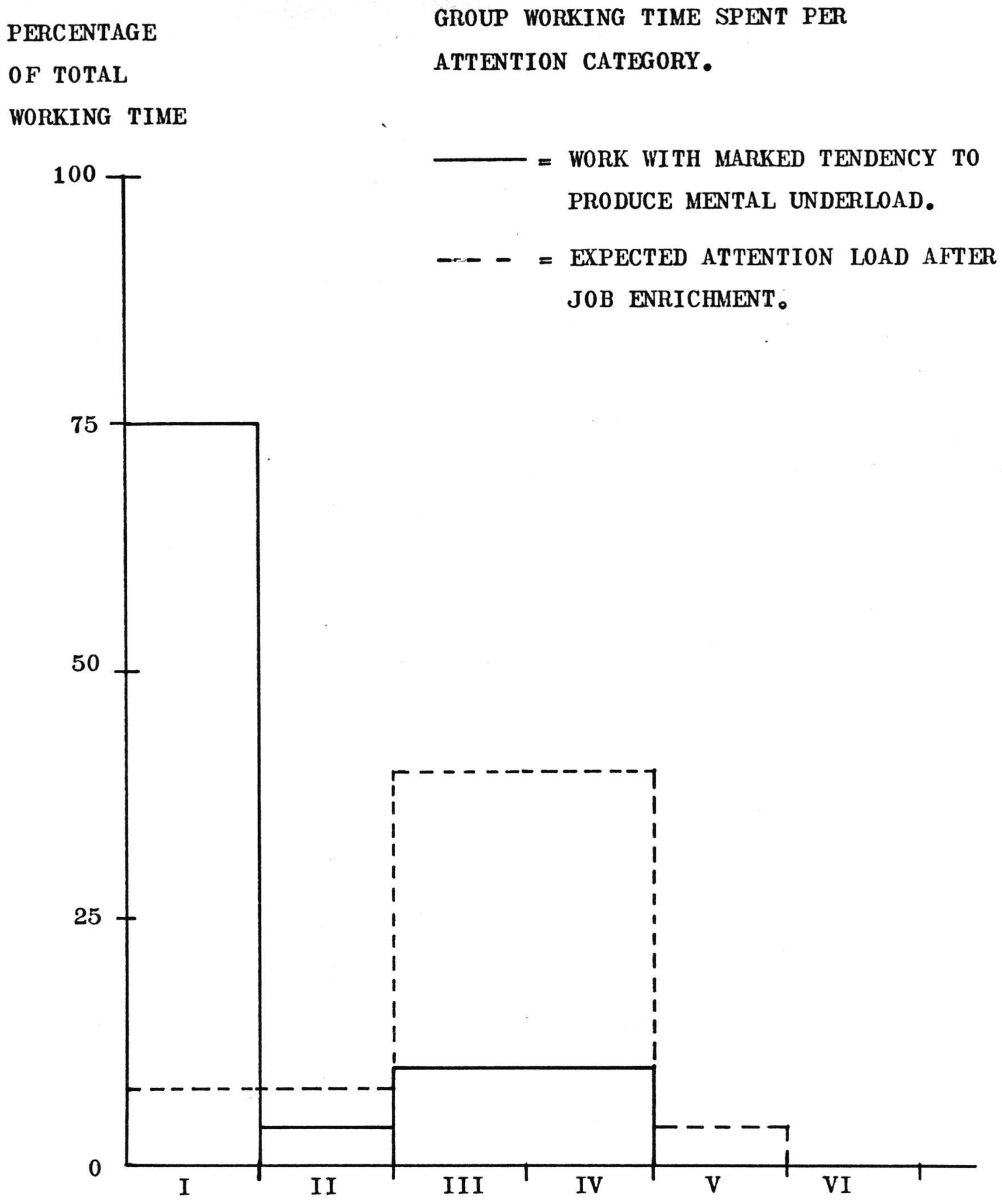

FIGURE 6. ATTENTION CATEGORIES

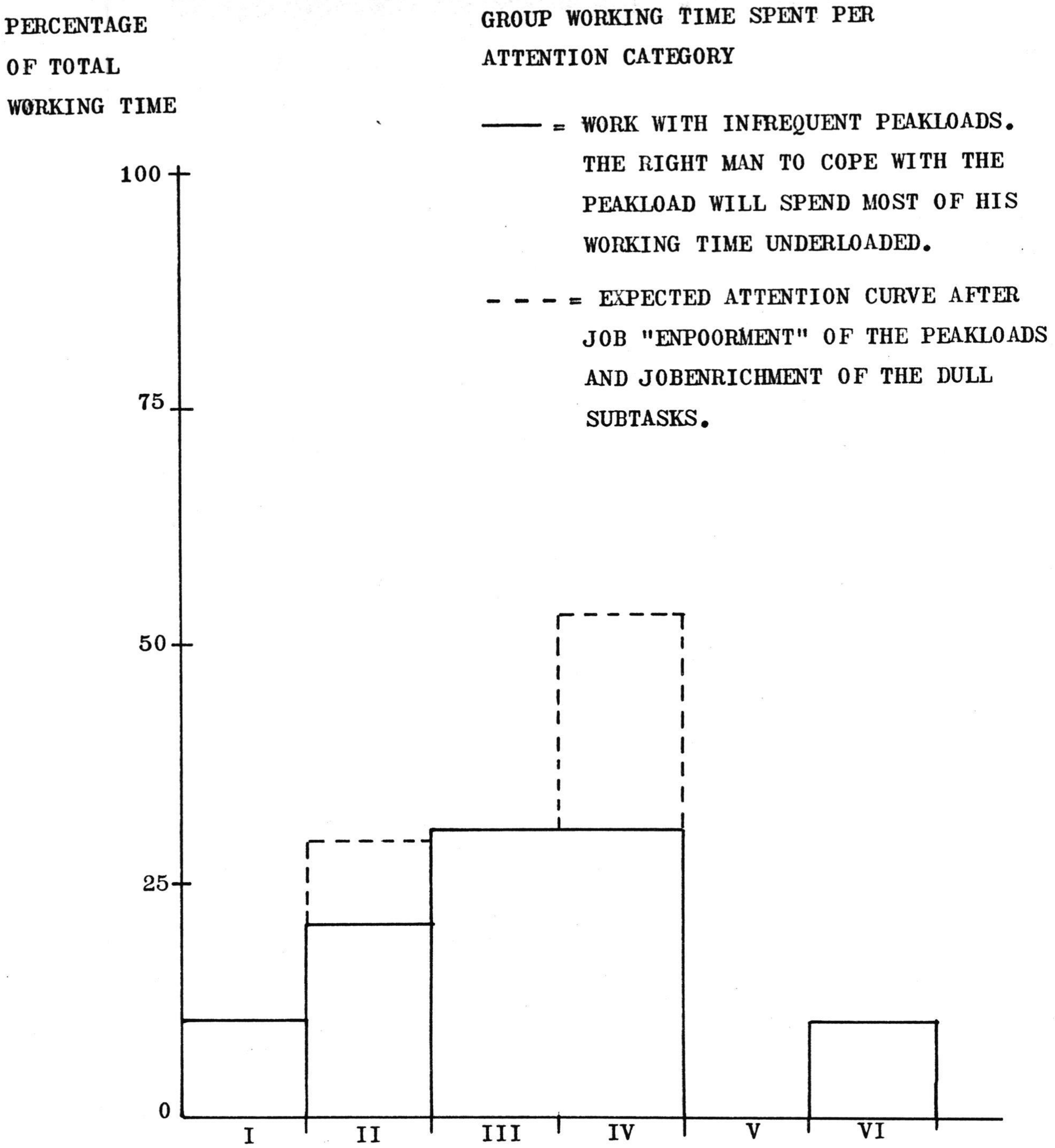

FIGURE 7. ATTENTION CATEGORIES

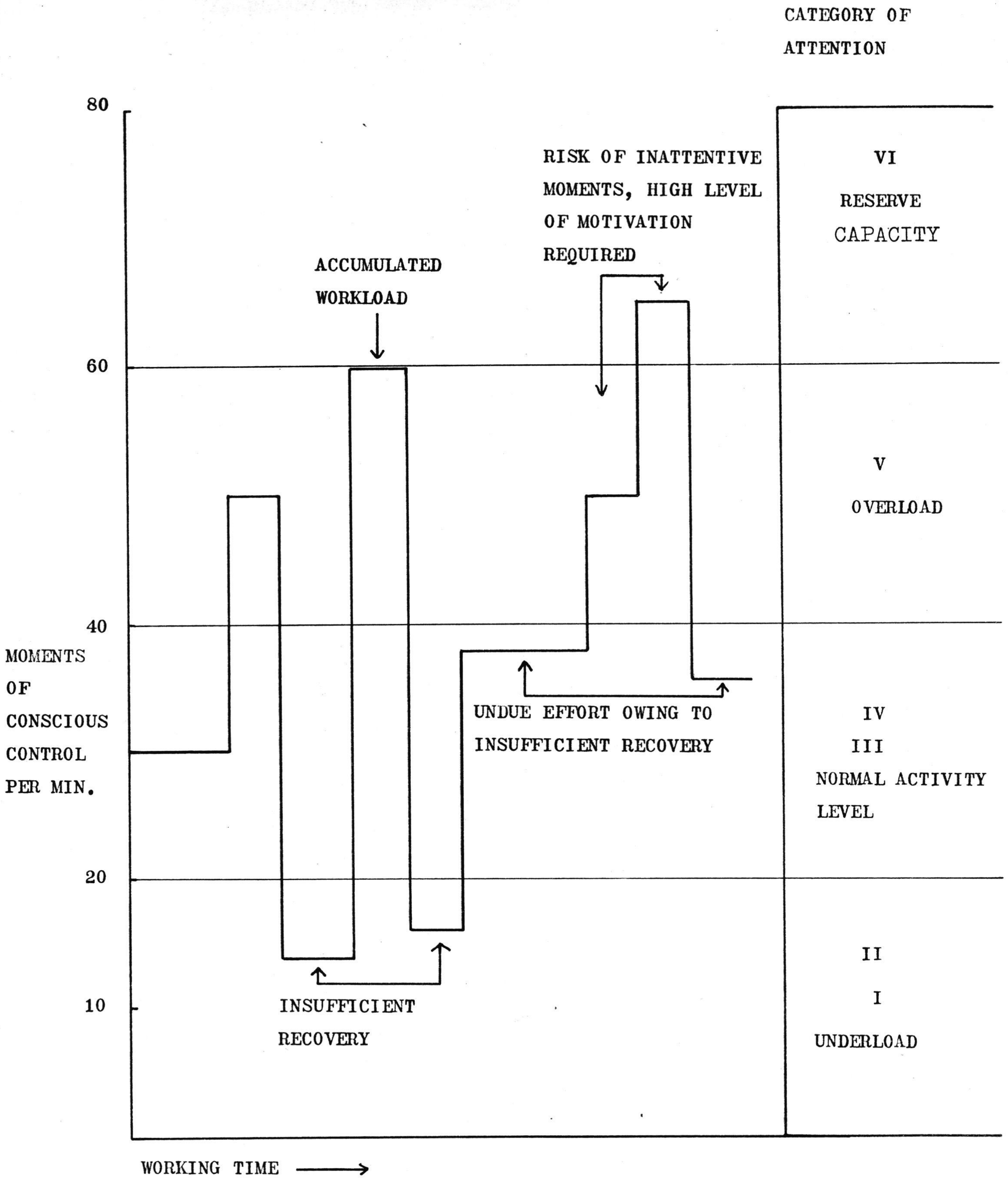

FIGURE 8. INDIVIDUAL ATTENTION CURVE DURING WORK.

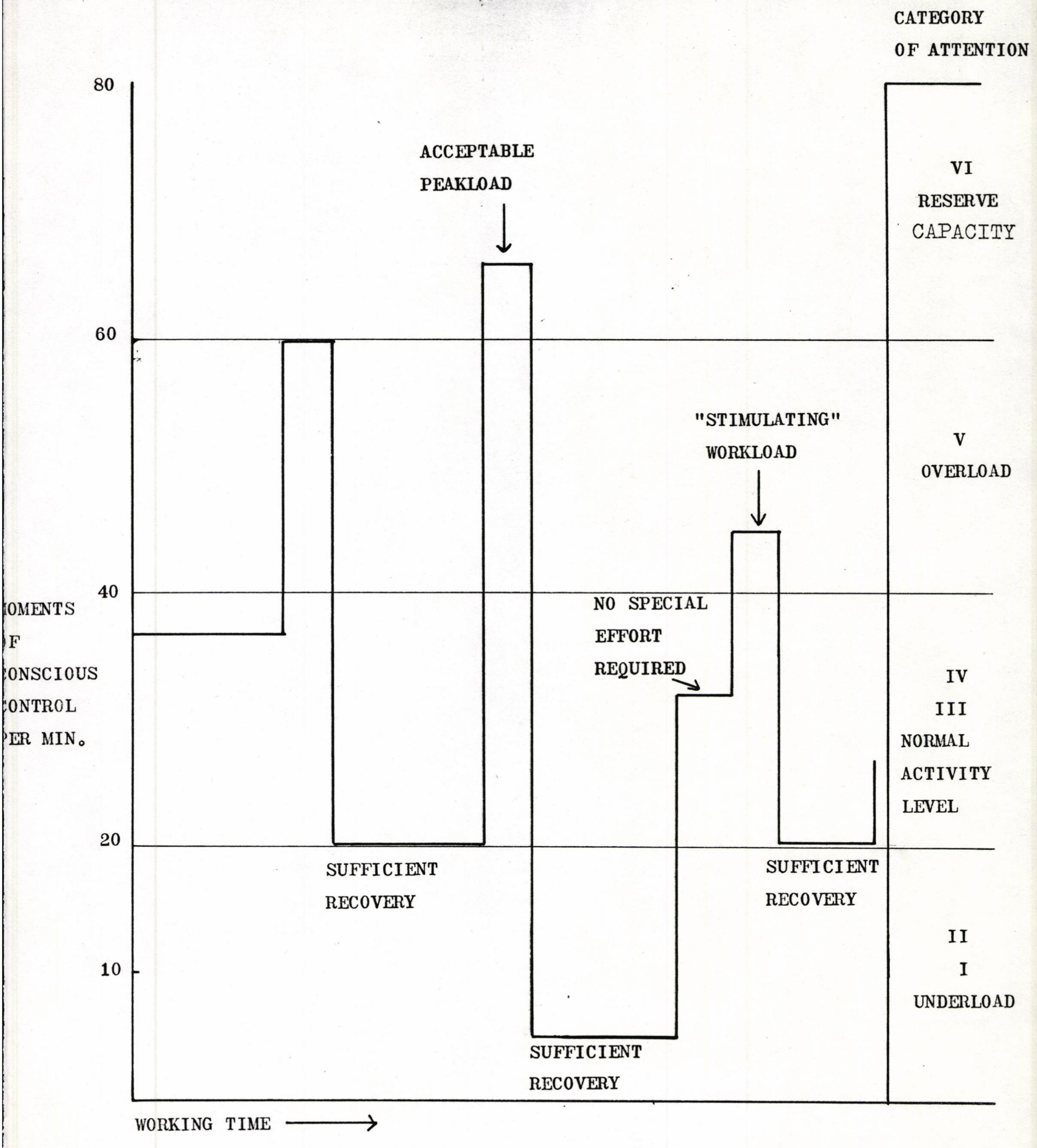

FIGURE 9. INDIVIDUAL IDEAL ATTENTION CURVE DURING WORK.