the cutilar products of the lamellas is the intermediate factor of the movements of the air in the lungs.

I must however still add that in special circumstances some more important movements of inhalation and exhalation can be observed, which are brought about by the operations of muscles of the body and of a special muscle of the vestibulum. I intend to discuss these in a subsequent communication.

Physiology. — "*On the nature and progress of visual fatigue*". By Dr. A. A. GRÜNBAUM (Odessa). (Communicated by Prof. G. VAN RIJNBERK) [1]).

(Communicated in the meeting of May 27, 1916).

The problem of visual fatigue has, in contrast with cognate problems as those of light- and darkness-adaptation hardly been broached from an experimental side.

The widely spread, purely theoretical views have from one side contributed to this fact, according to which the self-regulation of optically sensitive substances leads to a practical indefatigability. (HERING). On the other hand the traditional postulate, according to which the application of very strong optical stimuli in itself lies already beyond the physiologic limits of the pathological domain, plays an important part in the neglect of our problem.

Notwithstanding this I have only been conducted by purely experimental requirements and consequently selected strong stimuli, causing a positive fatigue. A 400 N. K.-lamp e.g., tempered by a milk-glass and placed at a distance of 1.25 m. from the experimental person, forms such a stimulus.

I have studied the progress of the fatigue caused by this light-stimulus by availing myself of the already often investigated phenomena of "flickering".

When we cause a light-stimulus to influence, intermittingly with a dark pause, on the eye, we can at a definite frequency of the succeeding stimuli no longer distinguish them; the impressions fuse, and from the flickering light the impression of a relatively quiet light is experienced.

The number of light stimuli (and consequently likewise that of

[1]) The results recorded here form part of a series of experiments made in the years 1914—16 in the Physiological Laboratory of the University of Amsterdam, serving to obtain the venia legendi in experimental psychology at the Medical Faculty there.

the intermissions) at which the impression of fusion becomes just noticeable does not only depend upon the intensity of the intermitting stimulus (SCHENK, MARBE and others), but also upon the functional condition prevailing in the visual organ. SCHATTERNIKOFF e. g. has found that the frequency at which the fusion sets in, diminishes not only with a stronger intensity of the intermitting light, but also with a stronger adaptation of obscurity.

Some introductory experiments have taught me, that likewise a previous strong stimulus of the eye with the strong source of light described above diminishes the frequency for the fusion. There is no doubt a certain connection between the measure of diminution of the limit value (Schwellenwert) and the duration of the penetration of the stimulus of fatigue. The limit value for the fusion (i. e. the number of interruptions at which it just sets in) can serve as a measure of the fatigue prevailing at the moment of the experiment.

As however the results of some authors who occupied themselves with the analogous limit values, differ very considerably, I intended to find the cause of this fact, and to avoid it in my own experiments.

In the first place the moments mentioned already in literature that can cause the differences in the limit values were carefully avoided in a special apparatus. A constant light of a NERNST lamp, placed far behind a row of milk-glasses, is periodically interrupted by a massive metal dull-black-polished turn-disc with 12 equally cut out sectors. Before the disc a white screen was placed with a little opening fitting to the sectors. The illumination of the screen is always kept constant with the intensity of the light of the flickering hole.[1]) Further a maximum exercise of the experimental person is reached, and at last the relation is sought, at which the judgment of the experimental person is most stable.

It appeared that the experimental person must not wait during the experiment till the impression of an ideal rest within the visual field is reached, but must cease at a nearly imperceptible unrest within the optical field, as soon as this impression no longer changes with the further augmentation of the velocity of interruption. In reality the number of the interruptions per second at which the fusion takes place, is not taken into consideration as limit value The most positive limit value corresponds much more with the number of interruptions at which only the distinction of the separate stimuli is no longer possible.

[1]) The mechanism for the regular modification of the revolving-velocity and likewise a number of little cautions for the stability of the exterior conditions I describe in an elaborate publication.

The corresponding method by which the limit value is reached through a slow increase of the velocity of intermission, furnishes especially a stable value at a continuous and regular approach of the limit value. The average variations, when this method was applied, were in our experiments less than one period (the duration of one light-stimulus + an equally long absolute dark pause) per second.

(I draw attention to the fact, that these results, forming a methodical foundation, are in a certain contradiction to the usual indication of application which are spread in the practice of heterochromal flickerphotometry.)

The constancy of the determinations obtained with our method renders it possible, that one single determination is sufficient to characterise the momentary condition of the visual apparatus.

The single determinations succeeding one another can consequently serve to construe an illustration of the variations of this condition during the time of the determinations.

When applying *other* psychophysical methods I have found however, that the limit values in the same objective circumstances, in the same series of experiments are, at great variance with each other. When comparing different psychophysical methods I have further discovered, that the limit values found do not only vary according to the methods applied, but that the deviation becomes the greater as the intensity of the flickering light increases. This proves consequently that the difference of the psychophysical methods is not only connected with a difference of subjective factors, but also with a preponderating modification of objective physiological conditions.

The difference in the results of the few authors who have experimented with quite different methods, is consequently to be explained in the first place by the influence of these different physiological circumstances. With all succeeding experiments I have therefore always applied the same method, which may be called: the method of the uninterrupted, regular increase of the velocity of intermission till an optical impression that does not change any more is reached.

By applying this method, I have tried inter alia to solve the question whether the adaptation of light can be regarded as a state of relative fatigue.

For this purpose two series of limit values are compared; one consisting of determinations that were noted after a good adaptation of light (15 min. in the sun), the second series, those which were noted after a fatigue of the eye.

It appeared that the state of the visual organ adapted to the

light remained constant in the successive determinations of the limits. With the experimental person Wa. e. g. the limit value, that is to say at little, respectively average, or great brightness of the flickering light it was 28.6 respectively 23 or 20 periods per second.

After the penetration of the strong light-stimulus during 45″ respectively 90″ or 180″ the successive determinations which were each separated from each other by rest-pauses of 10 seconds and lasted even about 15 seconds, offered quite a different appearance.

I summarise the progress of the effect of the fatigue in Table 1.

This table teaches:

1. The longer the fatigue lasts, the more the power of distinction decreases in the first moment after the cessation of the stimulus of fatigue.

2. The norm, which the achievement indicates at a good adaptation of light, is however reached in about the same time. So the longer the fatigue lasts, the more relatively the process of relaxation takes place.

3. After the norm has been reached again, the power of prestation rises still higher above the norm and remains for some time so much the greater as the primary fatigue was longer.

This excess of compensation deserves our special attention.

4. The greater the intensity of the flickering light is, the less the prestation descends under the corresponding norm with the same duration of the stimulus of fatigue.

Point 1 indicates how the processes of fatigue constantly prevail more and more over the compensatory factors intervening simultaneously, when the duration of the irritation is increased.

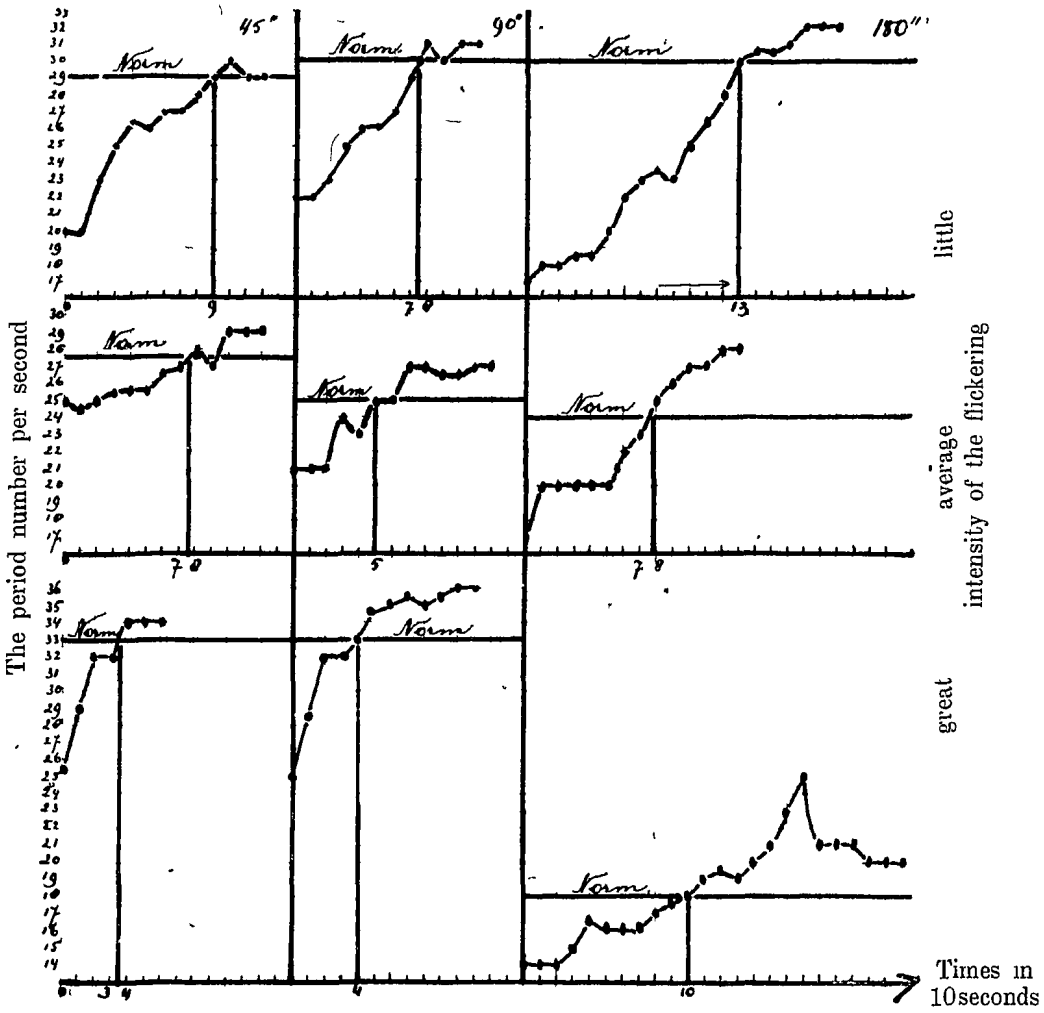
In point 2 the regulations of the efforts of the fatigue are formulated by the compensatory processes after the cessation of the stimulus of fatigue.

Point 3 indicates the relative duration of these compensatory processes after the relaxation has taken place.

Point 4 indicates that the consequences of the fatigue do not only depend upon the duration of the fatigue, but also upon the original stationary condition of the eye that is caused by the intensity of the flickering light.

The comparison of the limit values after the fatigue and after the adaptation of light shows consequently a principal difference between the two states. The adaptation of light is a stationary state of the eye which determines a constant height of the prestation. When this state has once been reached, then it is indifferent with regard to the time-factor. The fatigue on the contrary creates a

TABLE I. Binocular fatigue



process, or in better words, a modification of state, consisting of two antagonistical moments, which are dependent on the time-factor according to fixed laws.

From the controlling experiments, in which a constant width of the pupils had been obtained, follows, that the modification of the limit values represented in our curves cannot be attributed to a modification of the quantity of the light, which is connected with the reflectoric narrowing and gradually widening of the pupils at the strong irritation. The modification of the brightness of the surroundings of the flickering plane is likewise without influence. (This modification is always caused by the intensive gradually disappearing after-images of the stimulus of fatigue). The corresponding control has, namely, shown that in one and the same series of experiments

1st equal limit values can be obtained both when the after-images are still extant and when they have afterwards disappeared. 2ly Two succeeding limit values can also indicate a regular increase of the prestation, when the same subjective intensity of the after-images is stated. 3ly The weakening or strengthening of the subjective intensity of the visible after-images (reached by means of an adequate modification of the illumination of the screen round the flickering hole) remains without influence on the shape of the curve.

From the comprehensive problem of the nature of visual fatigue it appeared to me, that, for a concrete experimental answer, in the first place the question must be solved: where is the place of the processes of fatigue? Is it peripheral, central or both? In order to approximate the answer I have applied the following method. Two progress curves obtained by monoculary determinations at the same eye are compared together. In one series the same eye is fatigued, on which the determinations of the limit value are executed (direct penetration), in the other series on the contrary the stimulus of fatigue on the other eye (consensual penetration).

The experiments applied under constant adaptation of the not fatigued eye showed the image represented in table II (p. 173).

The results can be summarised in the following rules:

1. *There exists a consensual fatigue of the eye.*

2. The first occurring decrease of the prestation is greater at the direct fatigue than at the consensual one. In the examined limits of the intensities of the light this relation depends neither on the brightness of the flickering hole nor on the duration of the fatigue.

3. At the direct fatigue the norm is generally reached a little later than at the consensual penetration.

4. Up to the norm the curves have a tolerably equal process.

5. Then however the essential difference appears, that the direct fatigue causes the well-known over-compensation, which did not occur with the consensual irritation in the examined limits.

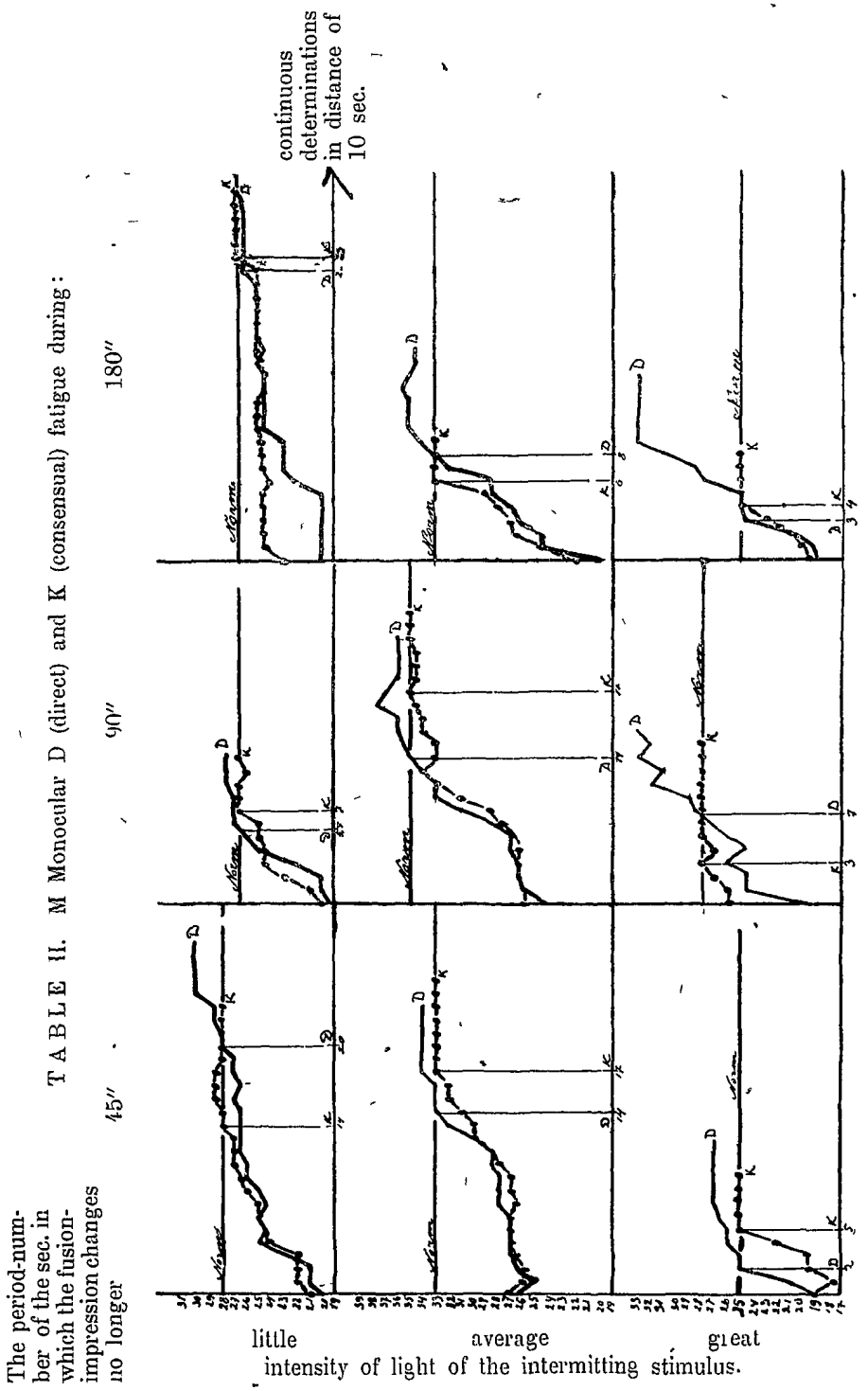
Points 2 and 3 may be summarised in the thesis, that the direct irritation of the eye causes greater fatigue than the consensual one. The explanation of this fact might be found in the self-evident circumstance, that in the case of the consensual penetration there is only a central component of the fatigue extant, whilst at the direct irritation there is still the dissolution (kataboly) of the substances, that are lying in the irritated eye itself, i.e. peripherally.

With this hypothesis of two components of the visual fatigue point 5 can be interpreted as follows. The results of the overcompensation are in the first place characteristic of the restitution of

the peripheral sensitive substances, because this over-compensation has only taken place at the direct irritation.

It stands to reason, that it still remains the question, if at less

TABLE II. M Monocular D (direct) and K (consensual) fatigue during:



important intensities of fatigue the direct irritation does not likewise cause over-compensation, and if at greater intensities, on the contrary the consensual irritation cannot likewise bring about such effects.

At the end we should compare the corresponding progress curves with the direct binocular and direct monocular penetration. We can, when doing so, sum up the deeper decrease of the limit values under the norm, the ulterior reaching of this norm and their afterwards coming higher above the norm, as a sympton of greater fatigue. The contemplation of table III added here teaches as follows:

TABLE III. Comparison of the results of the binocular and the monocular irritation of fatigue.

	Intensity of the glittering light	Duration of the Fatigue 45"	90"	180"	in general
Deeper under the norm	little	B	B	B	M
	average	M	M	M	
	great	B	M	M	
Higher over-compensation	little	M	=	B	=
	average	B	B	B	
	great	M	M	M	
Norm reached afterwards	little	M	B	M	M
	average	M	M	M	
	great	B	M	B	

B - Binocular, M - Monocular } Irritation of fatigue.

In our determinations the monocular irritation relatively brings about somewhat greater effects of fatigue than the binocular one. At all events the binocular irritation is not accompanied by greater effects than the monocular one. *Consequently there does not exist a binocular summation of the irritation of the visual fatigue*, which corresponds well with the analogous denial of the binocular summation of the subjective brightnesses (ROELOFS and ZEEMAN).