DARK ADAPTATION, NEGATIVE AFTER IMAGES, TACHISTOSCOPIC EXAMINATIONS AND REACTION TIME IN HEAD INJURIES*

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The detection of diffuse and minor brain damage remains one of the major diagnostic problems in neurology and psychiatry. The lack of appropriate indices of impaired cerebral functioning was especially noticeable in the study of patients suffering from head injuries. The majority of late post-traumatic conditions are characterized by a scarcity of neurological signs and the clinical picture is, in addition, often complicated by psychogenic superstructure. In the search for objective methods which would substantiate the presence of brain damage in these cases, attention was called to a number of visual functions which were shown to be sensitive indicators of changes in brain physiology. In view of these reports it seemed of interest to inquire into the value of visual functions as indicators of structural brain damage. Thus dark adaptation, onset of negative after images, apperception and comprehension following tachistoscopic exposure and reaction time were investigated in 57 patients with head injuries.

The diagnostic value of gross alterations of the visual fields following craniocerebral injuries is well established. The influence of psychological factors in the testing of visual fields is stressed by Gelb and Goldstein. These authors attribute the occurrence of ring scotomata and concentric restricted fields to fatigue following brain injury. Halstead reported on the dynamic visual field, that is, that portion of the peripheral retinal field that can be made to yield the threshold visual impression at the same instant that a form discrimination is being made in the region of the fovea. He found that campimetric and dynamic fields coincide in lesions of the occipital or parietal lobes, but that in frontal lesions the dynamic fields are restricted when compared to the campimetric fields. Investigation of the fields was not confined to examination with white and colored test objects only. Phillips called attention to the use of the flicker phenomenon in neurological diagnostic and Riddell demonstrated its value for the estimation of the density of scotomata. Werner and Thuma applied the same method in the investigation of two groups of mentally deficient children. The critical flicker frequency was lower for the brain injured group at each brightness

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level than it was for another group of mentally deficient children without signs of brain injury.

Another group of studies was concerned with deficient perception of motion and with apperception after tachistoscopic exposures. Werner and Thuma\(^2^4\) showed that children with brain injuries are defective in perception of apparent motion, though they are able to perceive real motion. Pötzl and Redlich\(^1^8\) described a case of occipital injury with inability to perceive real or stroboscopic movements. A case of occipital and cerebellar injury in which slow and stroboscopic movements could not be perceived at all was reported by Goldstein and Gelb.\(^7\) Ruesch\(^1^6\) examined acute head injuries with regard to the phi-phenomenon and apperception after tachistoscopic exposure. He found that only a small percentage of cases showed significant impairment. Goldstein,\(^8\) on the other hand, tends to stress the general value of the tachistoscope in the study of head injuries and Altenburger\(^1\) used the same method for the detection of visual field defects.

A third group of studies dealt with visual functions as indicators of altered brain physiology while the subjects were exposed to gas mixtures of low oxygen content.\(^5\) Evans and McFarland\(^2\) studied the effects of oxygen deprivation on the central visual field. They found that while the central visual acuity remains unaffected, the angioscotoma widens progressively with increasing oxygen deprivation until it obliterates almost the entire field. McFarland and Evans\(^1^0\) demonstrated increased thresholds of light sensitivity after dark adaptation. McFarland and Halperin\(^1^1\) showed decrease of foveal visual acuity especially at low illuminations. Gelhorn and Spiesman\(^5\) pointed out that there is a lengthening period for the appearance of negative after images under influence of \(O_2\) lack, \(CO_2\) excess and reduction in \(CO_2\) tension of the blood due to hyperpnea. They conclude that these conditions produce a lowered excitability of fundamental nervous mechanisms involved in vision.

The above-mentioned findings clearly demonstrate that the majority of visual functions are dependent on intact anatomical structure of the brain, normal cerebral circulation, and blood chemistry. However, psychological factors such as "attention" determine to a considerable extent the outcome of visual testing. Goldstein,\(^6\) Halstead,\(^8\) Ruesch\(^1^6,1^7,1^9\), and others have shown that the degree of awareness is lowered in patients suffering from brain disease or injury. Impairment of awareness, however, may also occur in distractable, self-preoccupied, or fatigued persons.\(^5,2^1\)

In the application of visual tests to head-injured patients, these different etiological factors must be considered. In late post-traumatic syndromes the frequent combination of residual signs of brain injury with personality disorders of the neurotic type made it necessary to correlate visual functions with intelligence and personality tests, and with information concerning the severity of the injury. I.Q. and presence of neurological signs are indices of brain damage, whereas the Minnesota Multiphasic Personality Inventory gives a measure of abnormal personality trends.\(^1^8\) A visuo-motor reaction
time test was included in order to analyze the role of the "speed" factor involved. The selection of the visual tests was based on the commonly accepted theory that dark adaptation, negative after images, and tachistoscopic perception involve different structures and integration levels of the central nervous system. Thus measurement of the light threshold after dark adaptation represents a simple process of perception. Examination of negative after images involves already higher cerebral functions and tachistoscopic examinations seem to require the greatest amount of "attention."

METHODS

1. Dark Adaptation: By means of a bio-photometer manufactured by the Frober Faybor Company in Cleveland, Ohio, and described originally by Jeans, Blanchard and Zentmire, scotopic vision was observed before and after exposure to a bright light.* The observations were made by determining the amount of light necessary for the subject to see 3 of the 5 points of a dice five-spot or quincunx punched out of a metal screen, when the light transmitted through the holes was of decreasing intensity from the left to the right of the quincunx. Six readings were taken: the first one when the subject was unadapted in order to explain the test; the second after 10 seconds in full darkness with eyes closed; the third one between 20 to 30 seconds after termination of a 5-minute bleaching period in which the screen with the five holes had been replaced by a bright light source shining through ground glass. The next 4 readings were taken at 2½-minute intervals each. The results were expressed in millifoot candles referring to the center dot of the quincunx. Since the data showed the greatest scaling of values for the reading after the 5-minute bleach, the results are presented in terms of this single reading only.

2. Negative After Images: By means of a Ballopticon, a slide with a picture of a black H on a light field was projected onto a grey-green wall. The size of the projected image was about 25 by 19 cm., the H about 14 by 15 cm. The subject was seated so that the distance from eyes to wall measured 1.6 meters. He was instructed to fix a small black spot on the wall marking the center of the image to be projected later. The illumination of the room was dim to assure the formation of negative after images. The slide was exposed for exactly 5 seconds and the subject was instructed to say "now" immediately upon perception of the negative after image (light H on a dark background). The period from the end of the exposure to the first appearance of the image was timed. Before recording the actual measurements, the subjects were trained for a varying period of time until the task was clearly understood. This was determined by the occurrence of similar values on consecutive readings. Following this trial period, additional exposures were taken and the mean value of the lowest five measurements was considered to be the latency period for the onset of negative after images. In a few instances the subjects reported that they never could see a negative after image and these cases were recorded as having a lengthening period of 30 seconds (failure).

3. Tachistoscope: A shutter with exposure speeds of 1/2, 1/5, 1/10, 1/25, and 1/50 of one second was attached to a Ballopticon. Slides with 3 digit numbers were projected onto the wall at the same distance and under the same lighting conditions as described for the negative after images. Five different numbers were shown in succession at each of the varying exposure periods, starting at the fastest speed of 1/50 of one second. The test reading was considered to be the shortest exposure at which all 5 slides were recognized correctly.

4. Reaction Time: A flash-light bulb was placed at a distance of about 1.6 meters from the subject, under the same lighting conditions as described before. The subject was instructed to press a hand push-button as soon as he perceived the light. Bulb and push-button were connected with a battery which in turn was in circuit with a relay. A pen attached to the relay recorded any opening and closing of the circuit on a moving tape, so that the reaction time

* I am indebted to Miss R. Gilman for the assistance given me in the course of this investigation.
could be measured directly from the tracing obtained. After a few preliminary trials, the mean value of 10 consecutive measurements was considered to be the representative test reading.

5. *Intelligence and Personality Tests*: Just before the patients left the hospital, they were given a shortened form of the Wechsler-Bellevue Adult Intelligence Scale consisting of Vocabulary, Similarities, Block Design, and Digit Symbol test. These four items were selected because of their high correlation with scores obtained with all eleven subtests. The examination time was thus shortened considerably without sacrificing the validity of the procedure. In addition to the intelligence tests, the Minnesota Multiphasic Personality Inventory and a specially prepared Complaint Scale were given to all subjects. The results obtained with these methods have been published separately.  

6. *Statistics*: Differences between means were considered significant when the difference divided by the probable error of the difference equalled or exceeded 4.0. Correlations were determined by the product-moment method. Following common use, coefficients ranging from 0 to 4 times the probable error of the coefficient of correlation were considered negligible, from 4 to 6 times as indicating a slight relationship, and above 6 times as expressing a substantial relationship.

**CASE MATERIAL**

Twenty-five unselected patients with recent head injuries (acute cases) were compared with 32 patients (chronic cases) who suffered from prolonged post-traumatic syndromes. In this latter group the accidents dated back from 6 months to more than 5 years. No diagnostic selection of cases was made except for the fact that the patients had to be cooperative and had to understand the instruction, thus excluding extremely dement and confused subjects. The case material used in this report coincides with the detailed description of head-injured patients given elsewhere. The majority of the patients were males, except for 3 females, in each series. Ages and I.Q. of the patients are given in Table 1. In 15 of the acute and 15 of the chronic cases there were signs of brain damage as evidenced by bloody spinal fluid, inequality of tendon reflexes, presence of pathological reflexes, cranial nerve palsy, convulsions or confusion. In addition to the patients, 25 hospital employees were subjected to the same tests; 17 of these were females, 8 were males. Though these subjects do not constitute a matched control group, the results obtained from this series helped in the evaluation of the data.

**DATA**

1. *Difference between Acute and Chronic Cases*. In Table 1 mean values and standard deviations are given for the various test results. The figures for

<table>
<thead>
<tr>
<th>Number of Cases</th>
<th>Dark Adaptation</th>
<th>After Image</th>
<th>Tachistoscope</th>
<th>Reaction Time</th>
<th>Intelligence</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mill-foot candles</td>
<td>Latency period in seconds</td>
<td>Exposure in hundredths of 1 second</td>
<td>Reaction time in tenths of 1 second</td>
<td>I.Q.</td>
<td>Years</td>
</tr>
<tr>
<td>25 Acute Cases</td>
<td>2.8</td>
<td>1.4</td>
<td>13.3</td>
<td>7.8</td>
<td>6.3</td>
<td>5.7</td>
</tr>
<tr>
<td>32 Chronic Cases</td>
<td>1.7</td>
<td>1.4</td>
<td>7.6</td>
<td>2.8</td>
<td>3.6</td>
<td>5.1</td>
</tr>
<tr>
<td>25 Controls</td>
<td>—</td>
<td>—</td>
<td>7.1</td>
<td>2.8</td>
<td>2.6</td>
<td>3.1</td>
</tr>
</tbody>
</table>
the acute cases are more abnormal than those for the chronic cases; the con-
trols have the lowest, that is, the most normal values for all three types of
cases studied. Between the controls and the acute cases, statistically signifi-
cant differences exist for all the variables. In the acute cases the onset of
negative after images is significantly lengthened as compared with the
chronic patients. The difference obtained between acute and chronic cases
for tachistoscopic examinations approaches significance: the difference of
the means divided by the probable error of the difference \(D/PE_d = 3.0\)
indicates that there are 97.9 chances out of 100 that this constitutes a true
difference.

### TABLE 2

Intercorrelation of test results

<table>
<thead>
<tr>
<th>Dark adaptation</th>
<th>After images</th>
<th>Tachistoscope</th>
<th>Reaction time</th>
<th>Intelligence</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark adaptation</td>
<td>+.23</td>
<td>+.08</td>
<td>-.03</td>
<td>-.11</td>
<td>+.53</td>
</tr>
<tr>
<td>After images</td>
<td>+.57</td>
<td>+.42</td>
<td>+.36</td>
<td>-.27</td>
<td>+.93</td>
</tr>
<tr>
<td>Tachistoscope</td>
<td>-.15</td>
<td>-.04</td>
<td>+.50</td>
<td>-.41</td>
<td>+.92</td>
</tr>
<tr>
<td>Reaction time</td>
<td>+.03</td>
<td>+.01</td>
<td>+.20</td>
<td>-.25</td>
<td>+.33</td>
</tr>
<tr>
<td>Intelligence</td>
<td>.00</td>
<td>-.01</td>
<td>-.10</td>
<td>-.13</td>
<td>-.35</td>
</tr>
<tr>
<td>Age</td>
<td>+.15</td>
<td>+.38</td>
<td>+.56</td>
<td>+.23</td>
<td>+.15</td>
</tr>
</tbody>
</table>

### CHRONIC CASES (32 patients)

2. Association with Age, Intelligence, Personality and Complaints. In
order to analyze whether these differences are an expression of brain injury
or of other factors, the results obtained were correlated with age, intelligence,
the Minnesota Personality Inventory, and the Complaint Scale. From Table
2 one can see that, in the acute cases, dark adaptation is to a considerable
extent a function of age \((r = +.53)\). The onset of negative after images is in
both the acute \((r = +.32)\) and chronic \((r = +.38)\) cases to an equal extent
influenced by age; intelligence seems to prolong the onset of after images in
the acute cases to a minor degree \((r = -.27)\). Tachistoscopic results seem to
be a function of intelligence in the acute cases \((r = -.41)\) and of age in the
chronic patients \((r = +.56)\). Reaction time in both groups of patients is
fairly independent of intelligence \((r = -.25\ and -.13)\) but is to a minor de-
gree a function of age \((r = +.33\ and +.23)\). Correlation of the results with
the Minnesota Multiphasic Personality Inventory and the Complaint Scale\(^8\)
did not reveal any significant association.
3. **Association with Brain Damage.** In order to analyze the association of the test results with persistent signs of brain damage following the initial loss of consciousness, the method described by Ruesch et al.\(^\text{18}\) was used to classify the cases according to the severity of the injury. In addition, the patients were separated according to the presence or absence of neurological signs. Only the results obtained with the negative after images showed a significant separation of patients within the acute group: those with neurological signs had a latency period of 16 seconds, those without, of 8.4 seconds.

4. **Intercorrelation of the Visual Tests.** The intercorrelation of the various tests in the acute cases indicates that tachistoscopic results, negative after images, and reaction time are more closely related to each other \((r = +.36, +.42, +.50)\) than to dark adaptation \((r = -.03, +.08, +.23)\). In the chronic cases there exists a relationship between dark adaptation and negative after images \((r = +.57)\).

**COMMENT**

The interpretation of the differences found between acute and chronic patients is guided by consideration of the results obtained in the control group. Acute head injuries have the most abnormal values, while the figures of the chronic cases tend to approximate those of the control group. The onset of negative after images proves to be the most significant of the tests used. The lengthening period found in the acute cases holds in spite of age. It is associated to a moderate degree \((r = -.27)\) with low I.Q., indicating its relationship to intellectual impairment. The delayed onset is, in addition, a function of brain damage, since acute cases with neurological signs show a much greater lengthening than cases without such signs. In the chronic cases no association between latency period and intelligence or severity of the brain damage could be demonstrated.

Tachistoscopic apperception is delayed in the acute group and the difference between acute and chronic cases approaches significance. However, no association between presence of neurological signs and delayed apperception could be demonstrated. In the acute series, tachistoscopic results are related to intelligence \((r = -.41)\). This is probably an expression of intellectual impairment since tachistoscopic results in the chronic cases are independent of intelligence, but are rather a function of age, thus restricting the use of this method in late post-traumatic syndromes. The determination of light threshold after dark adaptation and reaction time did not yield significant differences between acute and chronic cases.

An explanation of the lengthening period for the appearance of negative after images may be found in some physiological findings. Lindquist and LeRoy\(^{9}\) showed that cerebral oxygen consumption and cerebral circulation are decreased in dogs following a head injury. Schnendorf et al.\(^{21}\) found reduced oxygen consumption in man after head injury, and Stone, Marshall and Nims\(^{22}\) reported post-traumatic changes in pH and blood chemistry. All these findings point to the fact that metabolic changes are present after
head injury. Since the latency period in negative after images is lengthened by O₂ lack, CO₂ excess and reduced CO₂ tension of the blood (Gellhorn and Spiesman⁵), it is safe to assume that similar factors might have produced the lengthening in our acute cases.

The causes for the prolonged apperception time after tachistoscopic exposure in the acute cases are difficult to determine. That this aspect is not related to personality is shown by the lack of association with number or type of complaints or personality inventories. The absence of any significant association with presence or absence of neurological signs, or severity of the injury, indicates that the tachistoscope measures one aspect of head injury which is not expressed in massive tissue destruction. Nevertheless, the slower apperception of the acute cases must somehow be related to the injury. As mentioned above, age and intelligence are determining factors in tachistoscopic examinations. Both progressing age and decline of intellectual functions are associated with decline of brain weight. Similarly clinical evidence points to the frequent occurrence of cerebral atrophy following head trauma in absence of any neurological signs. Therefore, it is possible that the delayed apperception after tachistoscopic examination may be an expression of minor or diffuse brain damage, a hypothesis which has been repeatedly stipulated by Goldstein.⁶ This theory is also corroborated in our data by other findings. It has been established elsewhere⁶,₁⁶,₁⁹ that slowing of mental functions is an outstanding sign of brain damage. The intercorrelations (⁺.₄₂, +.₃₆, +.₅₀) of tachistoscopic results, negative after images and reaction time, demonstrate the retardation and slowing of mental functions in the acute cases, whereas light threshold after dark adaptation shows much lower intercorrelations with the other tests (⁺.₂₃, +.₀₈, −.₀₃), probably because the time factor is not involved. With increasing recovery and remoteness from the date of the injury (chronic cases), the slowing recedes as evidenced by the low intercorrelations of the visual tests containing a time factor (−.₀₄, +.₀₁, +.₂₀). It would be a fallacy, however, to attribute the slowing of mental functions to the presence of brain damage only. Disturbances of attention, apprehension and fatigue may influence visual apperception²,²¹, and neurotic individuals often complain of such disturbances. One has to consider that the effect of injury is not only a physical one, but that the psychological shock suffered may frequently lead to the development of anxiety, apprehension and other neurotic symptoms. Influence of such psychogenic factors on the outcome of test results should, therefore, not be disregarded.

Another interesting aspect of visual functions in post-traumatic syndromes is revealed by the fact that dark adaptation correlates higher with negative after images than with any of the other tests (acute cases, r = +.₂₃; chronic cases, r = +.₅₇). This finding can be interpreted by the commonly accepted theory that "retinal" factors are more predominant in these two tests than in tachistoscopic apperception and reaction time in which "attention" and higher cerebral functions are involved.

Of incidental interest is the finding that I.Q. in the acute group declines
with progressing age \((r = -0.35)\), thus indicating that older individuals suffer a relatively greater intellectual impairment. This fact is corroborated by the clinical findings of slower recovery and greater incidence of confusional states after head injury in older individuals.

The experiences gained in this investigation lead to the conclusion that testing of negative after images and of tachistoscopic apperception are brief and practical procedures. Interpretation of the results obtained with these methods, however, cannot be done without consideration of factors such as age and I.Q. Extreme deviations, therefore, are useful and significant for diagnostic purposes only. For prognostic use, however, repeated tests on the same individuals are of great value. Improvement of performance is definite evidence of previous impairment, and lack of further improvement indicates that a relatively stable post-traumatic level has been attained. Thus it seems that visual examination methods have a definite place in clinical procedures, since they may reveal defects and show improvement where other methods fail.

**SUMMARY**

1. Light threshold after dark adaptation, latency period for onset of negative after images, apperception after tachistoscopic exposure, and visuo-motor reaction time were determined in a series of 25 patients with recent head injuries, in 25 patients suffering from prolonged post-traumatic syndromes, and in 25 control subjects.

2. The influence of age, I.Q., severity of the injury, presence of neurological signs, time elapsed since the injury, and personality features on the outcome of these tests are analyzed and discussed.

3. A lengthening period for the onset of negative after images could be demonstrated for patients with recent head injuries. The acute cases with persistent signs of brain damage had a significantly longer latency period than acute cases without such signs. Apperception after tachistoscopic exposure proved valuable in acute cases but was not associated with the presence of persistent neurological signs. Light threshold after dark adaptation and reaction time did not show significant differences between acute and chronic patients.

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