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ABSTRACT

This paper discusses the dichotomy between continually moving eyes and the lack of blurred visual experience. A discontinuous model of visual perception is proposed, with the discontinuities being phase and temporally related to saccadic eye movements. It is further proposed that deviant duration and angular velocity characteristics of saccades in patients with hypertonic motor impairment relate to information processing deficits. Stabilized retinal images of stimuli, which bypass the effects of deviant patterns of scanning and fixation in the model, significantly increase the ability of these patients to actively recall information presented for durations of less than three seconds, which is essentially greater than the duration of the single scan during reading. Implications of the informational components of evoked potentials and electrophysiology, for diagnosis of status of fundamental reading skills, figure-ground perception, objective refraction, and visual perception in general are discussed. Also, therapeutic intervention in basic deficits in the reading process is examined. (Author/WR)

OCULAR-MOTOR FUNCTION AND INFORMATION PROCESSING:

IMPLICATIONS FOR THE READING PROCESS

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INTRODUCTION

A difficulty frequently associated with reading disability in childhood is the inability of the child to attend to and select from various sensory stimuli impinging on him at any given moment. Attentional handicaps, especially those associated with reading disorders, have a marked visual component. Data has been reported which indicates that many children with such disorders demonstrate variable patterns of visual scanning and fixation and do not demonstrate anticipatory saccades (Leisman, 1975a; 1975b; Gitleman-Klein, 1975; Taylor, 1975). By the same token, the child may be unable to expect forthcoming stimuli as demonstrated by the absence of the contingent negative variation (CNV) or expectancy wave in computer averaged EEG potentials evoked sensory stimuli paired over time (see Grey Walter, 1964; Sutton et al.,1967). When paired presentations of stimuli such as flashes of light are presented over many trials, the interstimulus interval should show the CNV potential. This potential is frequently absent or reduced (N. Mackworth 1974) in these children. The sequential nature of the reading process, the ability to visually recognize small differences between similar items, the necessity to recognize and remember orientational differences and the importance of an adequate ocular-motor and visual processing apparatus become important considerations in the development of any model of the reading process.

A number of models of the reading process have appeared in the literature, particularly in the last few years (see Geyer, 1971). They differ in both approach and comprehensiveness.

Although most of these models tend to stress particular systems, in general they are not inconsistant with each other. For example, Roberts and Lunzer (1968) present a model which is based on uncertainty reduction. It involves input control, initial processing, visual to vocal conversion, accumulation and synthesis of information under the influence of motivational antecedents and feedbacks between systems. The model stresses processing throught stored language constraints. A model developed by Venezky and Calfee (1970) however is based on the search for and processing of the "largest manageable unit" (LMU). Their system includes high speed scanning, LMU input, syntactic-semantic integration of input while locating the nextLMU, feedback between stages and synthesis of information (comprehension). A flow of data from temporary stores to permanent stores is stressed. Goodman (1970) describes a detailed reading model which is based on the premise that reading is like a guessing game. The reader tests tentative decisions formed while processing minimal language cues selected through stored constraints and expectational guidelines. His model involves scanning, focus refining, cue selection, image formation, multiple testing (memory comparisons) and decision making processes, utilization of short, medium, and long term stores, feedback between stages and synthesis of accumulating data. The psycholinguistic steps of the coding process are stressed.

J. Mackworth (1971) developed a model of reading which is essentially a summary and synthesis of what is presently known about the reading process (see figure 1). The Mackworth model has several important characteristics. These include: input involving selection, attention, expectancy and prediction; recognition through comparison to memory; synthesis of multiple inputs to establish context; coding, through motor-speech programs, into short term memory, with parallel processing of visual information under the influence of attention; synthesis of data and storage in long term memory. An interaction continually takes place between long term memory and all component processes.

Insert Figure 1

While J. Mackworth (1971) addresses herself to the total reading process it is the specific component of, and interactions between, eye movement, information flow, and information processing that are addressed here.

SACCADIC EYE MOVEMENTS AND VISUAL INFORMATION PROCESSING

A paradoxical effect appears to exist in the human visual system. If our eyes move all the time, which they do, we should have blurred perception of the object of regard, which we do not. On the other hand if our eyes were to remain stationary, the effect of which is duplicated in stabalized retinal image techiques (Riggs et al, 1953), perceptual fragmentation would result.

There must be some method of accumulating and storing information that would account for and explain such situations.

Scanning and Fixation Eye Movements

In normal vision the eye is moved to scan the visual scene and bring the retinal image of different points of interest on to the area which has the best visual acuity, the central fovea. This scanning is made by fairly sharp movements associated with fixation pauses during which the eye move comparatively slowly. In reading, for example, the eyes make several fixation pauses in scanning a single line of print and at the end of the line, it flies back sharply to the beginning of the next line. (Taylor, 1975). Much more complicated patterns of scanning and fixation pauses are involved when a subject views a picture (Yarbus, 1967).

These movements involve rotations of the visual axis through several degrees. They can be performed under conscious control, though normally the subject is not aware of them. Certain eye movements remain even when a well-trained subject endeavors to fix his gaze as steadily as he can on a well defined mark (Yarbus, 1967).

These movements include:

1. A fairly slow drifting movement with a velocity of up to 5 min. arc/sec.
2. Sharp saccadic movements whose excursions vary from 1 min arc to 30 min. arc (and occasionally more); the time required for one of these movements is nearly independent of the excursion and is approximately 1000 min. arc/sec. for a saccade of 12 min. arc
3. A high frequency tremor with an amplitude if the order of 0.3 min. arc. this is a noise-like movement with a power spectrum highest in the frequency range below 10HZ but with detectable components of up to 150HZ.

Median values for various parameters associated with these movements are given in Table I. There is a considerable variation in the values obtained with one subject on different days and a longer variation between the median values for different subjects.

Insert Table I

Even the eye movements of fixation are fairly large in comparsion with the smallest detectable movements of an object in a visual field which has a structural background. The angular diameter of the moon is, for example approximately 30 min. arc. Many of the saccades are approximately one-third this size and some are as large or larger.

If the moon were making sharp movements of approximately one-third of its diameter several times per second, our vision of the craters on its surface would be greatly impaired. Yet, the retinal image of the whole visual world is making such movements. It follows that visual perception always involves recognition of patterns which are moving rapidly and in an irregular way. This is true not only of the recognition of a road sign by a viewer in a moving car, but also when an individual examines a pattern and believes that his eyes are stationery with respect to a fixed point in the visual field.

The system of conjugate eye movements is subject to the influence of higher brain centers. Impulses transmitted from frontal, parieto-occipital and temporal fields of adversion may provoke an eye movement in the contra-lateral direction. The effects of the impulses arising from each of these fields differ. Among the foremost functions of the frontal lobes are the voluntary motor impulses The frontal fields of adversion make it possible to look up-down and left-right voluntarily. The occipital fields of adversion enable individuals to pursue visual stimuli.

Insert Figure 2

Axonal fibers of the fourth order neurons, whose cell bodies lie in the lateral geniculate bodies, form the geniculocalcarine tract which leads directly to the primary visual area of the cortex In man, this area approximately covers the striate region of the posterior occipital pole of each cerebral hemisphere.

Insert Figure 3

In the visual projection area, impulses are received from a given spot on the ipsilateral retina of each eye. Impulses from the lateral geniculate bodies also reach the various layers of the cortex.

The center for visual attention is also the center for conjugate eye movements, which extends from the region of the posterior and the anterior quadrigeminal bodies down to the abducent nucleus at the border of the lower and middle third of the pons (Glonig et al., 1961).The center consists of: the larger cell nuclei of the ocular-motor, trochlear and abducent nerves; a large number of small cells which became denser in the rostral portion to form CAJAL'S and DARKSHEVITCH'S nuclei; caudally, the para-abducent nucleus. There are also close fiber connections between the individual parts which consist, in part, of short fibers and long fiber bundles. The long fiber bundles unite and cross sides in the posterior commissure.

The system of conjugate eye movements causes the eyes to always be moved jointly in the same direction. This permits an individual to gaze up-down and left-right. Independent movements of a single eye become possible only in the case of convergence, in paralysis of the extra-occular muscles or after loss of an eyeball. Hoff and Osler (1957) and Leisman (1957a) have reported that the system of conjugate eye movements is closely connected with the tectoreticular system and with attentional process in general.

The center for conjugate eye movements is in turn, influenced by other cortical and sub-cortical areas. The cortical areas are called fields of adversion since they may provoke eye movements (see figure 3).

From the frontal fields of adversion in area 8, fiber connections run primarily to the caudal part of the region under discussion and primarily to the para-abducent nucleus.

In the same way, fiber links from areas 18 and 19 (the parieto-occipital fields of adversion and the region of the second and third temporal convolutions) pass through the posterior limb of the internal capsule, and the lateral portion of the cerbral peduncles where it then crosses sides to reach the region controlling conjugate eye movements.

The fibers arising in the frontal field of adversion pass through the internal capsule and the medial portion of the cerebral peduncles Impulses are also received from the involuntary motor system, i.e. the extra-pyramidal system (Hoff and Osler 1957; Glonig et al., 1961).

The extra-ocular muscles can be activated, voluntarily or by reflex action. While most eye movements are of the reflex type, including those subserving the reading process, the reflex involves the visual cortex.

<u>Developmental Considerations of Saccade Characteristics</u>

The clarity of perception depends on the precision with which saccadic rotations are performed. The amplitude of the rotational saccadic eye movements depends on the strength of the muscle contractions and on the properties of the eyes as an inertia system (Gatev, 1968; Robinson, 1964)

Yarbus (1956;1957) noted a rising exponential dependence between the duration and amplitude of saccades and a rising linear dependence between angular velocity and amplitude. Robinson (1964) has shown the relationship between saccadic duration and amplitude in normal adults to be linear up to 45 deg. in amplitude ($t=21=2.2\alpha$ (msec.) Where t=duration and α= amplitude. Yarbus (1956) calculated that for adults, $t=21\alpha^{2/5}$.

Gatev (1968), on the other hand, found that for one to three year old children, $t=17\alpha^{2/5}$ and for five to six year old children, $t=20\alpha^{2/5}$.

Westheimer (1954) had reported that the relationship between velocity and **amplitude** is non-linear and that the maximum velocity increases as a function of the eye **amplitude**. Gatev (1968), on the other hand, reported that the functional dependence between angular velocity and **amplitude** is rectilinear in normal children and with a saccade of the same **amplitude**, the velocity is greater in the case of younger children. For one to three year old children Gater reported that $\bar{\omega} = 90.6+14\alpha$ and for children aged five to six years, $\bar{\omega} = 59.3+13.9\alpha$ (where $\bar{\omega}$= mean angular velocity). With a saccade of the same **amplitude**, Gatev found the duration to be longer and the velocity lower in older children which was explained by age conditioned changes of the moment of inertia of the eyeball.

Leisman (1975b) reported that with spastic-hemiplegic patients, an increase in the **amplitude** of the saccade results in a concomitant increase in the mean angular velocity which is consistant with previous studies. With a saccade of the same **amplitude**, the duration is shorter and the velocity greater in hemiplegic as compared to normal subjects. Gatev (1968) reported significently greater velocities for young normal children than Leisman (1975b), Robinson (1964), Yarbus(1956; 1957) and others found for normal adults. Although no direct evidence exists, it is possible that maturation requires greater precision of saccades with a result being a decrease in saccadic velocity with increasing age (see tables II and III).

The hemiplegs exhibited a greater mean angular velocity than did normal (Leisman 1975a; 1975b) for a saccade of the same **amplitude** These results cannot simply be explained on the basis of the immature nature of the nervous system and muscular development.

Insert Table II

Insert Table III

With an increase in the amplitude of the saccade, not only the mean but the maximum velocity increases in both normal and hemiplegic subjects (Leisman 1975a;1975b). This indicates that the character of this function and the differences observed between normal and hemiplegic subjects, is conditioned, in part, by the differential effects of extra-ocular muscle contractions. One can expect greater velocities and shorter duration if the extra-ocular muscles contract with more force. The reasons for such observed differences have not been determined, but may well be due to spasticity associated with such conditions as hyperreflexia or involvement of inhibitory mechanisms.

Leisman (1975a;1975b) has reported that the dispersion of the velocity amptitude function increases in brain-damaged subjects. An analagous dependence also exists for the duration/amplitude functions. The increasing variability of these functions in hemiplegic may represent differences between the functioning of their eye control system and that of normals.

The visual-perceptual system must be able to extract information about spatio-temporal changes in the enviroment from the "stable" and redundant features. This is basic to any theory of information transmission. There is also a necessity for removing information which is not relevant to the immediate situation (Jacobson, 1951).

Each saccade is a controlled quantity upon which the clear reception of visual information depends. The eyes perform each saccade at a maximum velocity which provides an opportunity for attaining the necessary precision and insuring the prompt supply of information required.

The existance of functions $t(\alpha)$ and $\bar{w}(\alpha)$ permits an exact preliminary program of the duration of future saccadic eye movements. However, the greater variability of these functions in brain-damaged patients makes the preliminary determination of the future saccades more difficult and less exact than for normal individuals.

Filtering and Transmission of Information

The objective facts of how vision occurs have long been known to be inconsistent with the subjectively experienced temporal continuity. The eye is never completely at rest. In ordinary viewing of the visual world and especially during the reading process, the eye jumps between two and four times a second (Young and Stark, 1963). Each jump displaces the retinal image.

Visual input cannot be continuously presented to the brain as we experience it but is presented in "chunks" (Gaarder et al., 1964; 1966; Leisman, 1975c) at a rate and a time determined by the rate and time of saccadic eye movements. The necessity of a filtering system of information processing can be illustrated by a simple calculation (Jacobson, 1951). If we consider the number of receptor fields and the number of nerve fibers, it appears that the retina can collect information at the rate of 10^7 bits/sec and the million channels in the optic nerve can transmit at a similat rate (see Leisman, 1975c). On the other hand, psychophysical studies on pattern recognition indicate that the information used in recognition of a pattern is seldom more than about 40 bits (Leisman, 1975c). This is a large amount of information since 40 bits enables one out of 10^{12} possible patterns to be distinguished but it is small compared with 10^7 bits/sec.

Part of the reason for this discrepancy is that 10^7 bits/sec. could only be effective in a situation where all patterns viewed consisted of random arrays of small black and white areas. Moreover, for full usage, the random pattern should change in a random way about 20 to 30 times per second. In reading we are concerned with a visual scene in which the length of bounderies between light and dark areas is extremely small compared with the length in a random pattern. Irregular bounderies are extremely rare in comparsion with regular bounderies.

Changes in the visual situation during reading occuring within 50 msec. are usually small and are seldom completely unexpected. All of these considerations reduce the number of possible patterns which could possibly be encountered. A decision which confirms what already has a high probability of being true has only a small information content. Most of the visual judgements in reading should be of this nature. Nevertheless, pattern recognition in reading may, and often does, involve very critical judgements. It is also difficult to say in advance which little piece of visual information is going to be critical. Letter "A" may be recognized by "∧" or by "_" or by "⌐\". A word recognition may work in a similar fashion. In any event, the whole elaborate visual system is needed in order to make available the ten, twenty or forty bits of information required for a recognition.

Rattle and Foley-Fisher (1968) and Leisman (1975c) have suggested that a person who is performing task summates information during the intervals between saccadic eye movements, but cannot carry foward the precise information from one interval to the next. It has also been demonstrated that if a subject has too frequent saccades, he could not make a good vernier setting. A relationship also exists between accuracy on the vernier task and the average time used in making a setting. The results are consistent with the hypothesis that information is summed for times up to 200 msec.

Hubel and Wiesel (1965) noted that information is first filtered and then subjected to a process in which the precision of retinal location is sacrificed for more precise identification of pattern features. The slow movements of the eyes by which the pattern is gradually transferred from one set of retinal receptors to others, must be compensated for so that the logical structure of the pattern appears as a constant of the visual scene. The compensation probably breaks down during the involuntary saccades and during the more rapid semi-voluntary movements.

There is much evidence in support of the contention that when a rapid movement is initiated, a partial block is inserted in the perceptual system so that visual sensitivity diminishes by two or three times (Volkman et al., 1968). This block operates a few milliseconds before the movement commences and lasts until it is finished. During this stage, the subject perceives the pattern as being steady and unchanged even when flashing rapidly across his retina. (Leisman 1973,1974, 1975d) has noted that the ability to condition the EEG alpha blocking response as well as the ability of hemiplegics to recall information is improved when visual stimuli are retinally stabilized. This indicates that eye movement variables may play an important role in attentional a[illegible]ing deficiencies. Differences have also been shown to exist in the variability and precision of saccadic eye movements between normal and attentionally handicapped subjects (Leisman 1975a, 1975b).

These differences discussed in the preceding section, can be explained in part, by differences in the strength of extra-ocular muscle contraction (possibly related to the lack of inhibitory control in hemiplegics), differential effect of inertia and spring stiffness of the eyeball (maturational factors) and learning variables (i.e.deficiencies in the mechanisms of anticipation-learning of saccadic eye movement, control and precision). This latter possibility is of interest in terms of N. Mackworth's (1973) finding of an absence of the <u>expectancy</u> <u>wave</u> or anticipatory response in reading deficient children.

Lindsley (1952) thought that stimuli were coded upon input to aid in perceptual clarity. He conceived of a mechanism in which saccadic eye movements are linked with EEG alpha activity. The saccades occur during an inexcitable phase to avoid retinal discharge impinging on the cortex. Meister (1951) noted a significent relationship between the onset of saccadic eye movements and the alpha rhythm. Gross et al. (1967) reported that visual evoked potentials were reduced during eye saccades. The possibility of visually detecting a flash is reduced during a saccade and the ability of a flash to evoke a pupillary response is also greatly reduced (Zuber et al.,1966). It is possible to propose a simple physiological hypothesis that assumes that inhibitory neural interaction is common to vision and to photopupillary motion.

Gaarder et al. (1966) found a component of EEG alpha activity which was temporally related to the occurance of saccadic eye movements. They found phase locking to be present prior to the onset of saccade. It was thought, therefore, that the saccade does not serve as a stimulus which locks the alpha activity into phase, but that alpha activity reflects the driving of the saccades. This points to a discontinuous nature of visual perception with the discontinuities being related to the characteristics of saccadic eye movements (see Leisman, 1975c).

Harter (1967) received the notion of cortical excitability and scanning and showed how the rate of scanning fixation saccadic eye movements is parallel to the state of arousal of the subject. He also noted that the additional attentional task of processing speech drastically increases the rate of saccades in some subjects (Gaarder 1967).

We have previously noted indications that the characteristics of saccades are different in subjects with information summation defects than in normal individuals (Leisman, 1975b). It has also been indicated that with stabalized retinal image procedures, subjective reports of attention state as well as the ability to condition the alpha blocking response improves in attentionally handicapped subjects.

If the alpha rhythm has been reported to be related to saccadic eye movements, (Lindsley, 1952; Meister, 1951; Gross et al., 1967; Gaarder et al., 1964; Leisman 1973, 1974, 1975a), and if the differences which exist in the duration and velocity of saccadic eye movements of subjects with attentional and information processing deficits are related to the ability to perceive and integrate visual information in the cortex, then manipulating the eye movement variable (i.e. deviant characteristics of eye movements which are counteracted by techniques which stabilize images on the retina) should result in changes in the alpha rhythm related to attentional states and improvement in the ability of these subjects to recall information. Leisman (1973,1974,1975a) has reported data consistant with these notions.

John et al. (1967) noted that when generalization occurs, a stored representation of prior experience is recalled by a novel stimulus. The neural activity underlying the recall of this prior experience was reflected by the evoked potential components. The essence of John's thesis is that slow waves can reflect the storage and retrieval of information. The neural representation of information stored in the brain is not, in his opinion, the activity of certain hypothetical coded cells which "stand for" specific items of information, but is rather certain spatio-temporal patterns of organized activity. Simply, what can be inferred is that the evoked potential carries information and that this information is transmitted in a discontinuous fashion, with the discontinuities linked to saccadic eye movements. Saccades of short duration and high velocity can well lead to difficulties in the processing of visual information . What emerges then is a picture of visual perception as a discontinuous process with the discontinuities temporally and phase linked with saccadic eye movements. Information is transmitted in bursts linked in time to the fixation pause when visual sensitivity diminishes. It has been previously noted that saccades of short duration and high velocity may be related to information summation **deficits** and to difficulties in performing critical judgements. These difficulties have been significantly improved by techniques which manipulate the variable of saccadic eye movements.

The Role of Saccades in Pattern Recognition and Reading

Mackay (1967) proposed a model in which stimulus intensity was encoded logarithimically at a peripheral stage. At a more central stage, the organism generates a "matching response" to incoming neural signals. Mackay noted that an internally-generated matching response to signals from sensory receptors would "amount logically to an internal representation of the features in the incoming signals to which it is adaptive," and proposed the matching response as a physiological correlate of perception (Mackay 1956; 1966;1967).

Central to Mackay's model of perception as an active "updating" process, a view which because of its generality, would be difficult to disprove. Mackay's is a comprehensive model of perception only to the extent that perception can entirely be described in terms of action and readiness for action or anticipation of action. In terms of the original problem of perceptual stability maintained in the presence of continually moving eyes, we had inferred a discontinuous model of vision with the discontinuities linked to saccadic eye movements. Several models of CNS activity, however, are concerned with this stability and involve the notion of <u>corollary discharge</u> which is initiated in the motor region of the brain simultaneously with the motor signals which will result in motor activity (Teuber, 1960). This discharge is then compared with subsequent incoming messages from the sensory system. The <u>difference</u> between the corollary discharge (representing the intended action) and the messages from the eye (which represents the action achieved) can either influence further action, or ascend to a higher center and produce a perception. In Mackay's model, the matching response does not conceal incoming signals but evaluates them.

Let us consider some results (Rattle and Foley-Fisher, 1968) alluded to earlier which suggests that a subject who is performing a critical task summates information during the intervals between saccadic eye movements but cannot carry forward the precise information from one interval to the next. These investigators have performed detailed studies of the accuracy of vernier-acuity judgments. In one experiment, a subject was required to move one straight line until it formed a continuation of a fixed line, kinesthetic and proprioceptive cues being excluded. This involved a judgment of whether the movable line was to the right or left of the fixed line and subjects with good acuity could detect a misalignment of less than 5 secs. of arc. A highly significant correlation was found between accuracy of the vernier setting and the intersaccadic interval (i.e. if a subject has very frequent saccades, he cannot make a good setting). These results are consistent with the hypothesis that information is summed for times up to 200 msecs. but that the summation has to be restarted after each saccade or word scan. We have also noted earlier the importance of saccade duration and velocity for information processing and how deviant patterns of scanning and fixation, when controlled by stabilized image techniques can result in the transmission of greater amounts of visual information.

Figure 4 illustrates the stages of visual discrimination based on fine detail related to the reading process based on the model of visual information transmission being developed.

Insert Figure 4

At the conclusion of a saccade, during reading, the eye is conditioned to assume an angular position, allowing for continuity in what is being read. Eye movements of fixation allow for the maximal activation of foveal receptors, thus providing the best visual acuity. At the same time reflected light from the printed page, while stimulating the receptors, is selectively filtered by a mechanical process. During this process the eye is oriented in such a way as to allow critical line and edge information.to align with the central fovea. However, as the foveal area accounts for approximately one third of the total area of central vision, the eye must oscillate within a range of no more than 20 deg. (Yarbus, 1967). This effectively and mechanically reduces the acuity of bits of information in the periphery of central vision, thereby creating a selective filter (Broadbent, 1958; Leisman, 1975) which emphasizes (a) the boundaries of letters and words and (b) new features. The information carried by the reflected light must be transduced by the receptors into potentials which are then transmitted through the visual system. However, as in other systems requiring transduction, there is an accompanying information loss (Leisman, 1975c).

We had noted earlier that normal adults demonstrate a predictable relationship between the amplitude and duration and amplitude and angular velocity of saccades. This relationship, while less marked, in normal children, indicating less precise saccades, is still more variable in hemiplegic patients with attentional and information processing disorders (Leisman, 1975 a; 1975b). As an individual scans a line of print, his eyes move from unit to unit until they reach the end of the line when they fly back and commence again on the following line. This involves the mechanism of anticipation and saccade predictability. N. Mackworth (1973) had noted that the anticipatory brain response known as the *contingent negative variation* or expectancy wave is frequently reduced or *absent* in children with reading impairment. The implication that follows is that the mechanism of expectancy requiring an individual to match a word pattern with a template in the first processor stage is disrupted. In the same way the angular substance of saccades during reading is conditioned by the position of the preceding saccade.

We had also noted earlier (Volkman et al., 1967) that during a saccade the visual sensitivity of the retina decreases by a factor of between two and three. The possibilities suggested as the cause of this decrease include a dynamic shift of the intraocular media relative to the sclera (Yarbus, 1967), partial perceptual inhibition (Yarbus, 1967; Alpern, 1964), or simply because the visual system has to deal with a retinal image moving at high speed (Yarbus, 1967; Alpern, 1964).

Another possibility is that when the eye rapidly moves over a relatively large area as it does during a saccade, light falling on any one area will be effectively reduced by its distribution over a relatively large retinal surface than during the fixation. Gaarder et al. (1964, 1966) and Leisman (1975a) have noted that the visual evoked response carries information and that the transmission of this information is phase and temporally related to the saccade. It is during the saccade then, that visual information is transmitted to the visual cortex which responds to the features of the visual stimuli (Hubel and Wiesel, 1965; Gaarder, 1967).

The first stage processor then matches bits of line and edge information from the visual cortex with templates, in order to complete initial encoding. This reduces the information to a form which can be processed further. Depending on whether effective matching has occured at this stage, a decision is then made for the regression of eye movements or for further processing. This regression occurs by influencing the eye position of subsequent saccades.

With the effective matching of patterns in the first stage processor, corollary discharge in the motor cortex allows for the comparison of subsequent incoming activity from the visual cortex and first stage processor. At the second stage processor, a recognized pattern is analyzed as being similar to an existing template in memory, or forms a new pattern consisting of component items previously stored (i.e. new templates stored in memory).

Saccade control, which is integral to the model, is maintained through the fields of adversion previously described. Saccades are controlled quantities and hence, specific words are viewed, by the establishment of a ratio between the amount of visual information needed and the amount of processing time needed. As we had previously noted, a controlled functional relationship exists between the amplitude of a saccade and its duration and velocity (Yarbus, 1967; Robinson, 1964; Leisman, 1975b). The fields of adversion, then, can influence the processing of visual information by influencing the amplitude of the next saccade. With high information levels to be scanned, one would expect saccades of relatively short duration and greater velocity. The system, as it relates to reading may be stopped by head movement directing eye movement away from the page scan.

With the establishment of new word templates based on known components and with the conclusion of primary processing and the influence of the saccade control system, a decision for either refixation or further and "higher" processing through other sensory systems, and linguistic and cognitive processes (J. Mackworth, 1971) is possible. If comprehension is achieved, the information is then synthesized for storage with the instruction to restart the process, if not, refixation occurs.

Figure 4 may suggest implicitly that the system of visual perception related to reading is like a rather simple computer that receives information, processes in various stages according to built-in programs and finally transfers it to "higher centers" which have a one-to-one correspondence with consciousness. This, of course, is a gross over-simplification - useful in a limited context, but misleading if naively accepted. If we must then liken the visual system to a computer, we must imagine one in which the final processor is able to call for many different analyses or parts of the information or even for some of the original data. It uses many different complex programs in order to produce a decision which results in action. Reading is only one aspect of this activity.

One implication of general systems theory that is of importance to our discontinuous model of visual information transmission as it relates to the reading process is the comcept of hierarchy of organization Shannon and Weaver (1963) have described this concept as it relates to language. A language at its lowest level, is made of a set of symbols (letters) and the size of the set (usually small) may be expressed in bits as indicated earlier. At the next hierarchcial level, a much larger set, "words", is made of groups of the symbols. In the hierarchy, the letters eventually become redundant concepts although redundancy still exists on this level in frequently occurring words such as "the". Still higher levels include phrases, sentences, chapters, etc.

Assuming that visual perception is a discontinuous process linked to saccadic eye movements, and occurring in bursts, then these bursts may represent hierarchcially higher units of visual information. It can also be seen that over time, vision consists of a chain of these units, as reading consists of a chain of words.

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Legend

Figure 1: Schematic model of the reading process (from Mackworth, J.F. Some models of the reading process: Learners and Skilled readers. In: Davis (Ed.) *The Literature of Research in Reading with Emphasis on Models* New Brunswick, N.J.: Rutgers Univ. Graduate School of Education, 1971, pp 8:67 - 8:100.

Figure 2: Starling's diagram of the action of the extra-ocular musculature (Brodal, A. *Neurological Anatomy* New York: Oxford University Press, 1969).

Figure 3: The relation between frontal, preoccipital and occipital eye fields and the midbrain nuclei for eye movements (Crosby et al., 1959).

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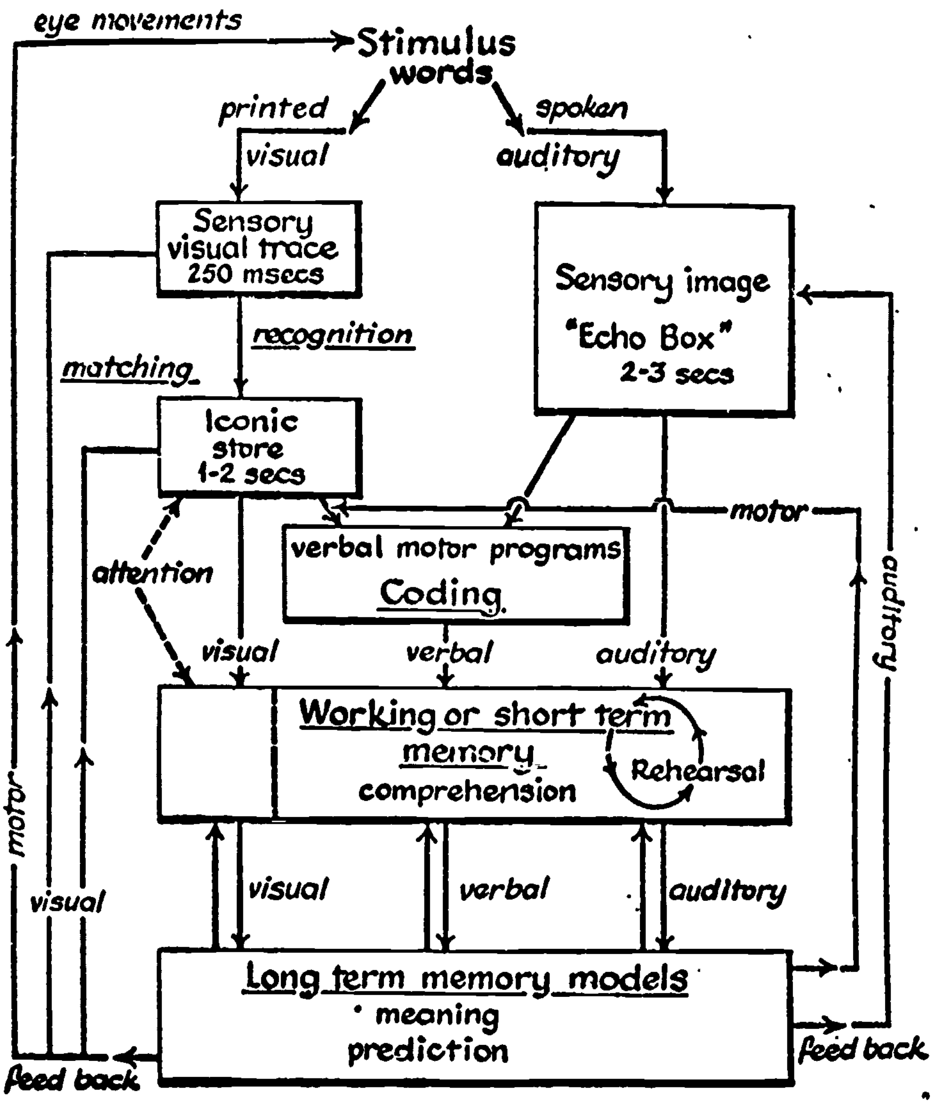
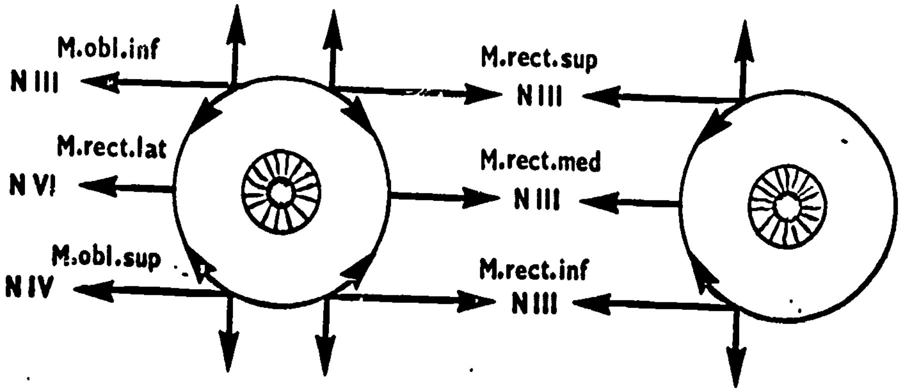
Figure 4: Model of visual information transmission in the reading process.

Fig 1



Model of Reading Process

Fig 2.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N III
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Fig. 3.

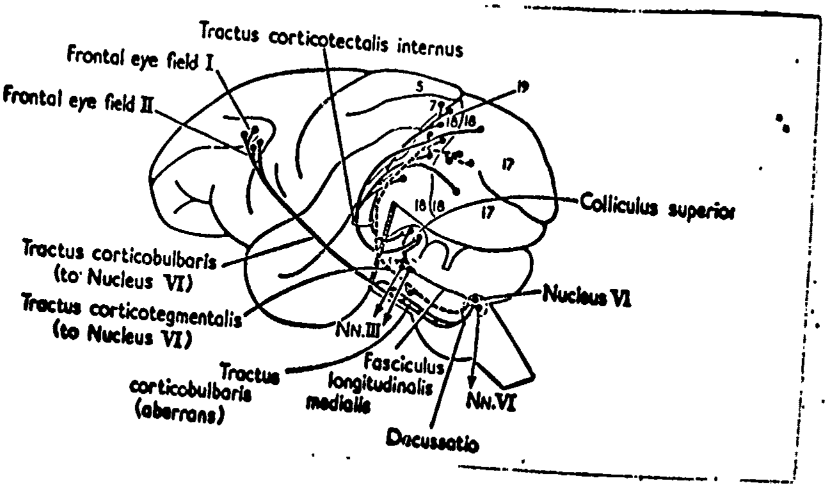
Tractus corticotectalis internus
Frontal eye field I
Frontal eye field II
5
7
19
18/18
17
18
17
Colliculus superior
Tractus corticobulbaris (to Nucleus VI)
Tractus corticotegmentalis (to Nucleus VI)
Nucleus VI
NN.III
Tractus corticobulbaris (aberrans)
Fasciculus longitudinalis medialis
NN.VI
Decussatio

Fig 4

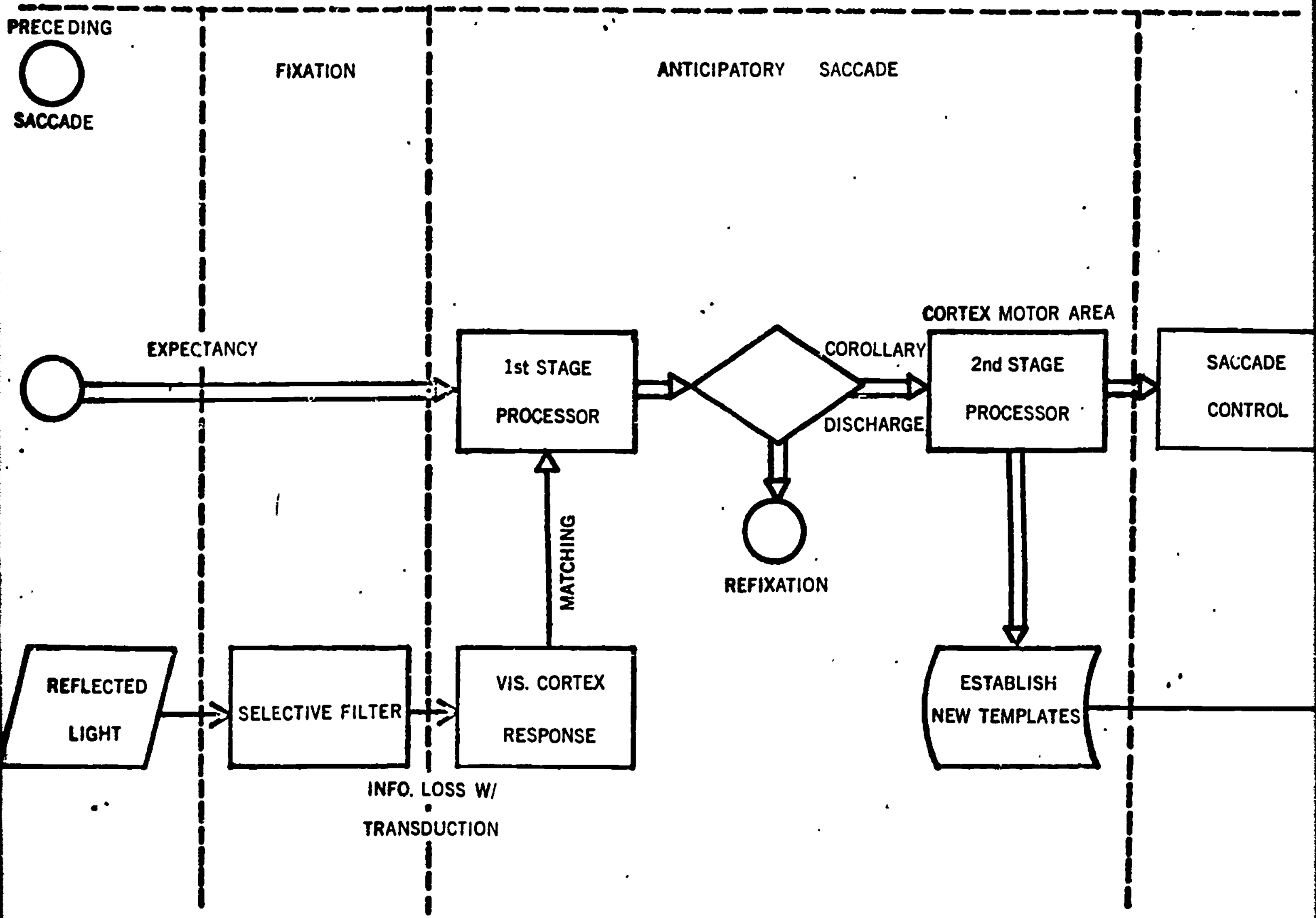
PRECEDING
SACCADE
FIXATION
ANTICIPATORY SACCADE
EXPECTANCY
1st STAGE PROCESSOR
COROLLARY
DISCHARGE
CORTEX MOTOR AREA
2nd STAGE PROCESSOR
SACCADE CONTROL
REFIXATION
MATCHING
REFLECTED LIGHT
SELECTIVE FILTER
VIS. CORTEX RESPONSE
INFO. LOSS W/ TRANSDUCTION
ESTABLISH NEW TEMPLATES

Fig 4

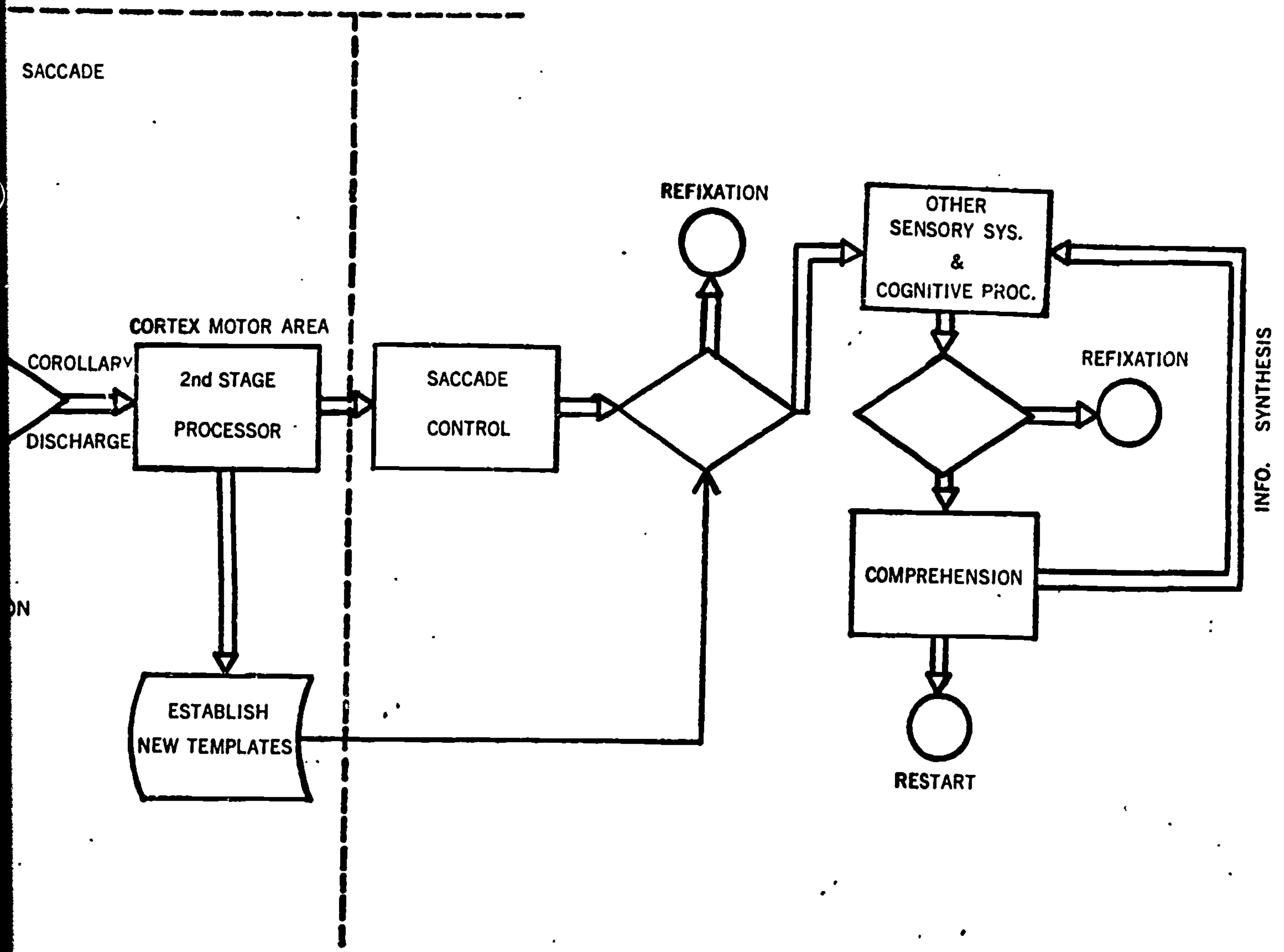
SACCADE
COROLLARY
DISCHARGE
CORTEX MOTOR AREA
2nd STAGE PROCESSOR
SACCADE CONTROL
REFIXATION
OTHER SENSORY SYS. & COGNITIVE PROC.
REFIXATION
INFO. SYNTHESIS
COMPREHENSION
RESTART
ESTABLISH NEW TEMPLATES

Table I

Median values for all subjects of parameters of eye movements of fixation. Fifty per cent of all subjects lit within the "Fifty per cent" range. Some subjects fall very far outside of this range.

	Saccade Amplitude (in deg.)	Inter-Saccadic Interval (in sec.)	Drift Amplitude (in deg.)
Median	4.5	0.58	2.5
Fifty per cent range	3.0 - 6.0	0.3 - 0.7	1.7 - 3.2

TABLE II

Amplitude (α), Duration (t) and Mean Angular Velocity ($\bar{\omega}$) of the Saccadic Eye Movements Obtained with Stationary Targets (Means Values)*(From Leisman, 1975b)

Group		2°-4°	5°-7°	8°-10°	11°-13°	14°-16°	17°-19°	20°-22°
Spastic-Hemiplegic	α	2.9	5.9	8.9	11.9	14.6	17.9	20.8
	t	24	35	44	47	46	50	55
	$\bar{\omega}$	140	167	215	280	333	371	387
Normal	α	3.0	6.0	9.4	11.9	14.9	18.4	20.9
	t	30	40	55	55	57	58	64
	$\bar{\omega}$	100	159	173	221	284	327	338

*The stationary targets were presented at subtenses of 15 and 30 degrees. Both smooth and saccadic eye movements were recorded. The movements were divided into seven groups depending on their amplitudes. Each group includes movements within a range of three degrees. Calculated for each group are the mean values of the α (in degrees); t (in insecs.); $\bar{\omega}(\frac{a}{t}x10^{3}$ deg.sec. $^{-1})$.

TABLE III

Amplitude (α), Duration (t), and Mean Angular Velocity ($\bar{\omega}$) of the Saccadic Eye Movements Obtained with Moving Targets (Means Values) + (From Leisman, 1975b).

Groups		2°-4°	5°-7°	8°-10°	11°-13°	14°-16°
Spastic-hemeplegic	α	3.0	5.6	9.0	11.8	14.4
	t	25	33	39	46	47
	$\bar{\omega}$	128	170	240	263	318
Normal	α	3.1	5.9	8.8	11.6	15.7
	t	32	41	49	53	61
	$\bar{\omega}$	98	138	183	228	268

+The moving targets were presented at the rate of either 12 or 30 deg /sec. Both smooth and saccadic eye movements were recorded. The movements were divided into five groups depending on their amplitudes. Each group consists of movements within a range of 3 degrees. Calculated for each group are the mean values of α (in degrees); t (in insecs.); $\bar{\omega}(\frac{a}{t}x10^3$ deg. sec. -1).