

The fronto-parietal attention network and the infantile nystagmus syndrome

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This article is dedicated to Prof Kehar Singh for his significant contributions to Optics and Photonics on the occasion of his 80th Birth Day (July 3, 2021)

We present an optical - information processing model of the human visual system, from casually moving the gaze onto an object to using the central executive network for consequent viewing decisions. We discuss how reflexive and conscious gaze-control decisions are made in the frontal eye field and the inferior parietal lobe, and initiate saccades. Cultural and spatial experiential learnings provide input to formulate our conscious decisions. We consider the consequences of the defective fronto-parietal attention network, presented by an individual with the infantile nystagmus syndrome on his viewing strategy and the potential limitations in his acquisition of visual information. We propose that such individual has near-nose convergence of eyes, and uses his eye muscles to reestablish gaze intermittently, with the eyes trying to return to their zone of comfort during each oscillation. This effort precludes healthy saccade employment. We conclude that an improper development of search mechanisms may result in a large amount of neglected information. © Anita Publications. All rights reserved.

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1 We point gaze to acquire information

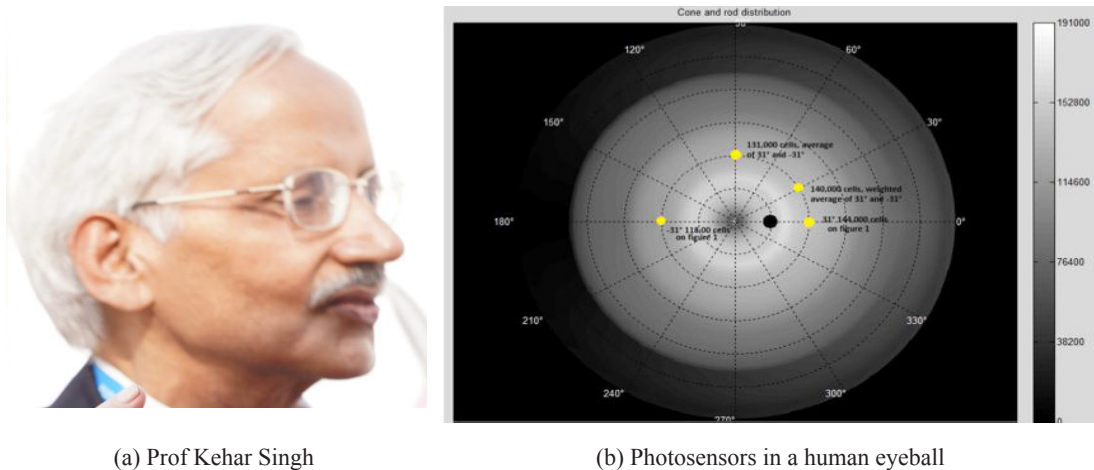
Humans rely most strongly on the vision sense for our daily functioning. Previously, we have presented a detailed comparison of the electro-optical system for information acquisition and the human visual system [1]. Here, we are interested in the improper functioning of the central executive network and a corresponding decrease in the amount of collected information. We only outline some salient points in this short note. In Fig 1 (a), we illustrate the process of vision with the gaze of Prof Kehar Singh during a discussion in Dehradun, India two years ago, on the occasion of International Conference on Optics & Electro-Optics. This paper has been submitted, on the invitation of Prof Vinod Rastogi, to a special issue of the *Asian Journal of Physics*, honoring Prof Singh for his significant contributions to physics and optics.

Two-dimensional (2-D) distribution of photosensors, rods and cones, as a function of cylindrical coordinates may be found upon interpolation from measured values along the line through the fovea and the blind spot. We can find sensor density along the same radial value ($\theta = \text{const}$), using the density at $\varphi = 0$ and $\varphi = \pi$ radians. The photosensor density is presented in Fig 1 (b) for the combination of cones and rods. Humans employ both of them in indoor environment.

The ring of the highest photosensor density is observed at about 20 degrees, although the amacrine cells actually decrease the acuity at these angles, resulting in an effective maximum resolution for the low-light vision at about 7 degrees. The pupil diameter increases to provide additional illumination to the high-acuity rods distributed near the optical axis [2].

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(a) Prof Kehar Singh

(b) Photosensors in a human eyeball

Fig 1. (a) Prof Kehar Singh (b) Distribution of photosensors, rods and cones, as a function of angles in a spherical coordinate system φ ($0 - 360^\circ$) and θ ($0 - 90^\circ$) on a half-sphere (inside surface of the eyeball). The density is calculated as a linear interpolation between the measured values along the horizontal line through the fovea and the blind spot.

The photosensors respond to the incoming radiation by a change in the molecular orientation. The return to the lower energy state introduces the change that initiates the response, with the voltage-peak repetition and intensity proportional to the amount of the absorbed radiation. The photosensor generates output to the bipolar and the horizontal cells. Horizontal cells communicate with other photosensors, to establish zero and local maximum for all cells exposed to the incident radiation. The bipolar cells are connected to the ganglion cells and the amacrine cells that interconnect all ganglion cells. They also decide whether the input from just cones or just rods is to be expected or from both sensors, thus adjusting to the expected level of the illumination.

About 25 different amacrine cells have been identified so far, mostly with the assistance of cats whose eye-function is quite different from and possibly superior to that of a human. Beyond 10 degrees, the ganglion cells limit the “camera-type” or “photographic” vision. The wide and narrow field-of-view ganglion cells may be connected in series for shape recognition and motion detection already on the retina.

2 Low-level processing in the visual cortex, V1

The human visual system (see [Fig 2](#)) includes all photosensors, inter-neurons, and neurons in the information chain that starts with a gaze at a point in visual scene to the primary visual cortex, V1. The optical nerve (2, one from each eyeball) carries the output from each eyeball. Each nerve includes about 10^6 axons of the ganglion cells. They converge in the optical chiasm (just one), where the nerves with the information about the right side of the visual field from each eyeball are brought together. The same happens with the nerves with the information about the left visual field. The aggrupation of nerves leaving the optic chiasm is referred to as the optic tract. The nerve bundles are input to a lateral geniculate nucleus (LGN) where they are further re-arranged into layers, from ventral (layer 1, stomach side), to dorsal (layer 6, back side) in preparation as the input to the visual cortex, V1. In particular, the stereo information with images from each scene point and detected by two eyeballs are collocated into the same stereo column.

The inputs from both eyeballs are collocated in the LGN layers, as we can appreciate in [Fig 2](#). The skewed line on the left indicates the direction of the gaze into the visual scene. The dotted lines follow the information from the right eye, while the solid lines follow the flow of information from the left one. The information from the left field of scene, detected by the right eyeball, is input into the layer 5 of the LGN; the

information about the scene's left field, detected by left eyeball, is input into layers 4 and 6. The information from the scene's right field, detected by the right eyeball, is input into layers 2 and 3; the information about the right field, detected by left eyeball, is input into layer 1.

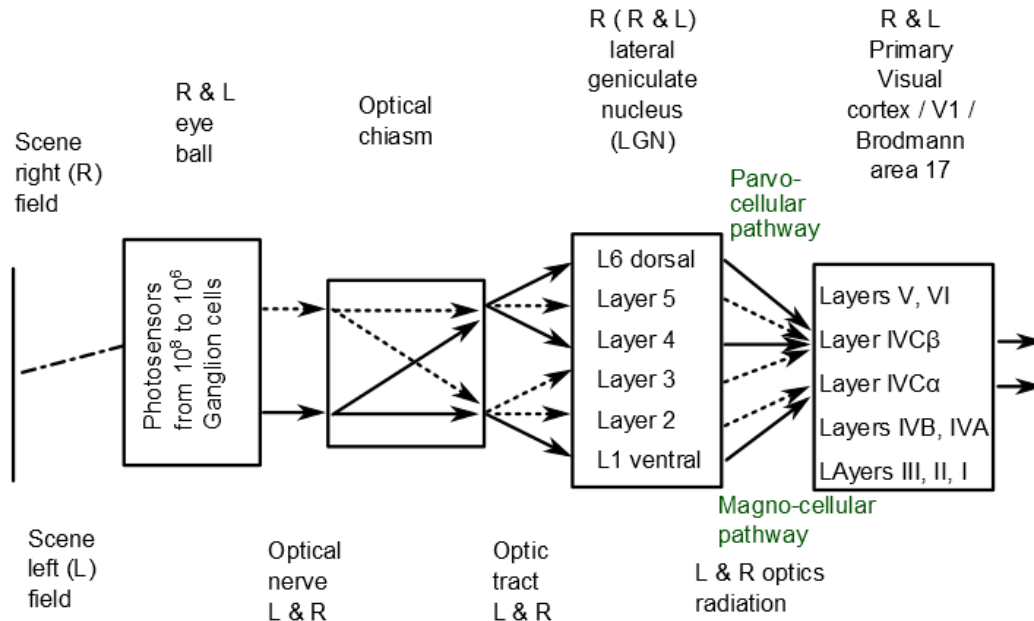


Fig 2. Schematic diagram of the human visual system: from gazing at a point in a visual scene to the primary visual cortex, V1. The dotted and solid lines follow the information from the right and left eye, respectively. The corresponding scene elements are arranged together inside the LGN in preparation for the low-level processing in the visual cortex. Separate channels for the magno-cellular (peripheral, large field-of-view cells) and parvo-cellular (fovea, small field of view cells) pathways are established as the output from the LGN. Only the forward direction of information travel is shown, although much neural feedback is incorporated along the way.

The LGN output is called the optics radiation. The grouping of the nerves indicates two neural pathways. The upper four outputs represent the parvo-cellular pathway (P), the projections of the ganglion cells with a small field-of-view. The ganglion cells transmitting the visual information originating on the fovea are mostly small field-of-view. They are input into layer IVC β of the visual cortex. The lower two outputs from the LGN represent the magnocellular pathway (M), the projections of the ganglion cells with large field-of-view. They are input into layer IVC α of the visual cortex.

When the information about the visual scene arrives in the visual cortex, the images from each eyeball were collocated for the calculation of the depth perception, and parvo-cellular and magnocellular pathways were established. At every step of information travel, there remains some correspondence to the initial visual scene, although the off-axis information is compressed radially due to the lower density of neurons afferent from there. This is referred to as the retinocortical mapping [3].

3 High-level processing: object recognition and spatial orientation pathways

The parvo- and magnocellular pathways are input into the areas IVC β and IVC α . From the area IVC β (P-cell input), the information is processed as to the shape and color (blobs) and placed into area I of the visual cortex, V1; blobs and stripes (inter-blobs) are stored into area II of the primary visual cortex; and orientations are placed into the area III. From area IVC α (M-cell input), the processing for direction is performed in the area IVB.

Optical information in the form of electrical signals travels from the primary visual cortex V1 to the higher areas where it is further processed in a serial and parallel manner, illustrated schematically in Fig 3. The object recognition is performed in the visual cortex V4 while the motion and navigation data is identified in the motor area MT or V5 area. Both information transfer strategies employ direct paths and side excursions through the secondary visual cortex, V2, or Brodmann area 18. In V2, the information is further processed according to color, stripe orientation, and depth perception. Much feedback is incorporated along the information processing paths, but we do not show it in our first order analysis.

We can see that the information processed in the V1-area is used as the input to the V2, V4, and the MT/V5 areas. Then the further-processed output of the V2 area is additionally provided as separate inputs to the areas V4 and MT. Both of these paths develop information about what object is in our field of view and what path to take for maximum likelihood of successful navigation (survival). From the V4 area, the ventral stream travels to the inferior temporal (IT) cortex. From medial temporal area (MT/V5) the dorsal stream proceeds to the posterior parietal cortex. It is associated with motion, representation of object locations, and control of the eyes, especially when visual information is used to guide eye movement and orientation.

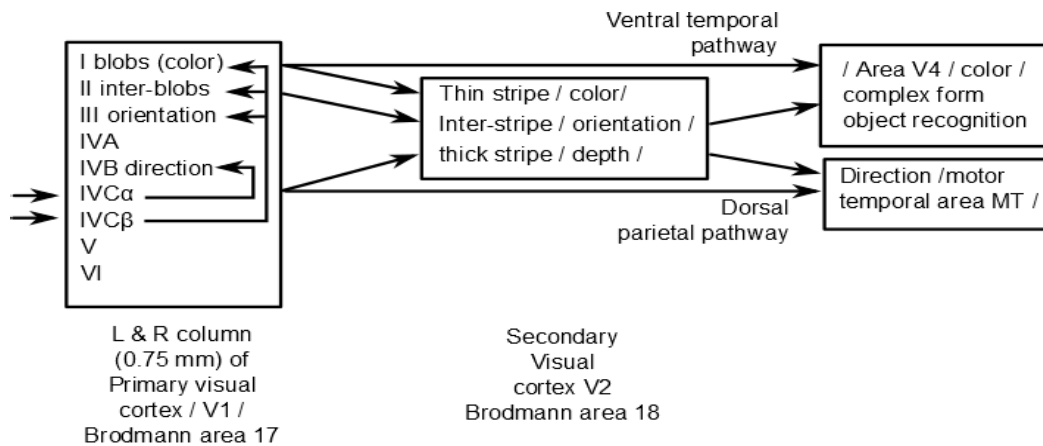


Fig 3. Higher order processing of visual input: from the input of M and P streams to the visual cortex (V1 area) to the object recognition (V4) and/or identification of navigational data in the motor area MT (V5). Both information transfer strategies employ direct paths and side excursions through the secondary visual cortex, V2, or Brodmann area 18. Only the forward direction of information travel is shown, although much neural feedback is incorporated along the way.

4 The central executive or the fronto-parietal attention network

Priority maps have been postulated as the centers on the cortex where a human decides upon the visual input whether to continue with the gaze direction and the task at hand or to switch the attention on the basis of new information that has just been introduced within the visual scene (like a black widow spider that has just crawled on your sleeve). The ensuing decisions may be reflexive or conscious. The conscious decisions are based on previous experience, or learnings, while reflexive decisions are dictated by the basic instincts. The reflexive decisions oftentimes require later logical justification and analysis for which adequate time did not appear to be available at the occurrence of event.

There is most likely a genetic component as to what constitutes the urgency, encoded as the *run-or-fight* imperative as well as experiential learnings. There is mostly cultural and experiential input to the conscious decision.

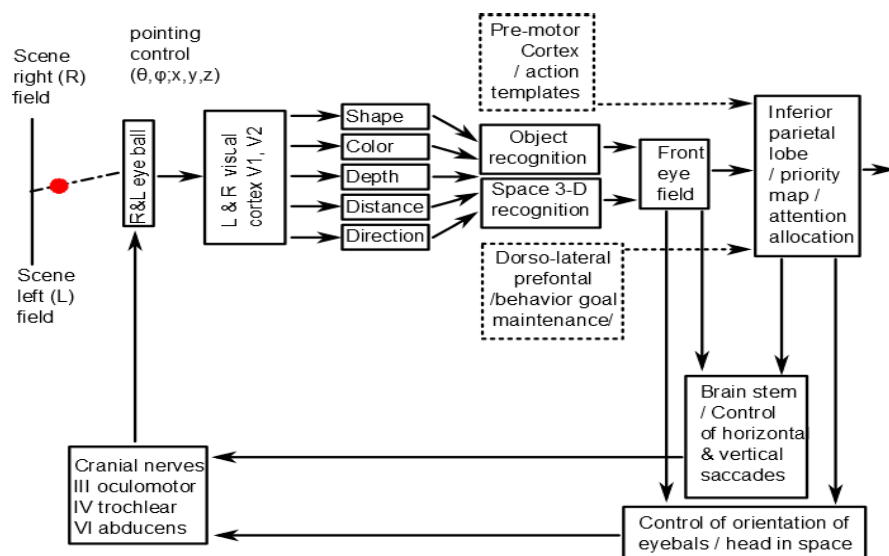


Fig 4. A simplified diagram of the central executive network or the fronto-parietal attention network. Only the forward direction of the flow of information is shown, although neural feedback is incorporated along the way. Despite the fact that the eyeballs are inside cranium together with cerebrum, the order to initiate saccades and direct attention, whether instinctive or conscious, travels through the brainstem.

The travel of the visually acquired information through the brain has been illustrated in Figs 2 and 3, without consideration of the time element. To differentiate between the instinctive and conscious decisions, we next compress Figs 2 and 3 and incorporate them into the left part of Fig 4. Dealing only with the visual input, although the auditory input may initiate similar decisions even more quickly, the inputs from the ventral temporal pathway for object recognition and dorsal, parietal pathway for the motion are received into and processed in the frontal eye field (2, one in each brain half). The frontal eye fields (FEF) are regions located in the frontal cortex (Brodmann area 8). They lie in a region around the intersection of the middle frontal gyrus with the precentral gyrus, thus including the frontal and the parietal lobes. We mention in passing that the changes in the scene introduce the motion. It, in turn, incorporates time.

The FEF sends information to the brainstem for the unconscious control of horizontal and vertical saccades. The brainstem also controls the position and orientation of the head and the eyeballs in space, within the constraints of muscle lengths. The eyeball control is accomplished through three cranial nerves, that is, the III oculomotor, the IV trochlear, and the VI abducens. The eyeball horizontal movement is controlled entirely by the medial and lateral rectus muscles. The oculomotor nerve controls the medial muscle; while the abducens nerve directs the lateral rectus muscle. The communication from the FEL to the brainstem and the cranial nerves is the short-circuit decision, used when *time is of essence*. An example of such decision is when you see hand approaching rapidly your face to hit you and you instinctively close the eyes.

The FEL also provides input for a conscious, longer-duration, and deliberate decision. It provides input to the inferior parietal lobe where a priority map allocates the attention. Other parts of the central brain provide input to the inferior parietal lobe. Concurrently, a pre-motor cortex offers action templates to suggest possible modes of operation [4]. At the same time, dorso-lateral prefrontal lobe offers behavior options related to the goal maintenance or its potential changes.

From here, the attention is potentially re-allocated, and the information again travels to the brainstem for the saccade control. This may be followed by the control of the eyeball orientation and even

head orientation and position in space to accomplish the revised goal. The same nerves and muscles execute the command in the consciously derived decision as in the subconsciously obtained one.

Within the brain architecture, the FEF orders an immediate reflexive action either to stay on the task (keep the gaze) or change it. The FEL also inputs this information to the inferior parietal lobe where a conscious decision, on the basis of additional input from other brain areas is made next. This input may include action templates from pre-motor cortex and behavior-goal maintenance, stored in the short-term memory in dorso-lateral prefrontal lobe. Other inputs would include the effects of the environment.

An example of a behavioral template would be that an experienced driver would put a leg on top of the brake pedal if he should see a car ahead of him exhibiting red brake lights, while both of them are driving at 100 km/hr (65 mi/hr) relative to the freeway. An example of the goal-maintenance would be if a mature adult would ignore texting while driving at the highway speeds. The inferior parietal lobe, thus becoming a conscious priority map, allocates the attention, on the basis of an informed decision. It may send the information to the brainstem to change the vertical and horizontal saccades for the object tracking or redirect the gaze to new object of interest.

These actions are controlled by the cranial (oculomotor, trochlear, and abducens) motor nerves, requiring the information to leave the forebrain. An order to acquire new visual-sensory input is issued to the eyeball about the new scene, in either space or time. "In space" requires the change in gaze direction. "In time" requires a new look at the old scene, incorporating time delay for temporal evolution. Either of these scene acquisition steps requires the repetition of the information travel through the whole loop.

5 The infantile nystagmus syndrome (INS)

We are actually exploring the visual function of individuals who are born or develop shortly after birth the so-called congenital nystagmus, nowadays referred to as the infantile nystagmus syndrome (INS). Nystagmus is a motion of eyeballs, in an uncontrolled, irregular, oscillatory and asynchronized manner with variable amplitude and frequency. The INS is horizontal, though vertical and circular also exist. A newborn does not actually receive much information (perceive) through his vision sense. He gets to identify light and dark blobs, like roughly oval feature of his caretaker's face. Then, he has to train his eyeballs to focus on things of interest, learn to follow moving targets, and develop the depth perception by looking at objects at different distances. In short, the caretakers have to provide the environment to train newborn's vision system to see. This is consistent with the blindness that sets in the mammals if their eyes are covered for critical period after birth. The featureless environment leads even adults to develop nystagmus, as demonstrated by miners who developed acquired nystagmus while they worked in darkness.

5.1 The cause of the INS

The exact cause of the INS has not been of interest, because it tends to be set aside as genetic or idiopathic, and, therefore, irreparable. One proposal is that insufficient stimulus is received to generate the neural response, as needed for the calcium ion channels. We believe that the no-input, least-effort orientation of each eyeball inside its socket is sufficiently misaligned so that their no-effort convergence would be just above the nose and not necessarily intersecting. This means that the right side of the right eyeball does not see anything within its left field-of-view, because the view is obstructed by the nose. Its left side of the eyeball sees the right side of the field-of-view. The left side of the left eyeball does not see anything within its left field-of-view, because the nose obstructs the view. The right side of the left eyeball sees the left side of the field-of-view. Both eyes handing the vision from one eye to the other see a complete field-of-view. We could also say that the INS subject has strabismus in both eyes.

An INS subject greatly enjoys reading his book with his nose (his eyes effortlessly converging on the letters). When the executive network tells the INS subject to look straight ahead, because a nagging child

needs a new band aid, the nerves and muscles that control the gaze comply, but with an effort. The eyeballs want to return to their lowest energy position, so they start oscillating between the position of required gaze and their position of comfort. The INS subject also starts to blink frequently. The INS individual examines the child's wound by scanning over it. Saying it differently, during a time a normal subject would examine one line of the scene twice, or perform ten saccades, the INS one would be acquiring information from a single scene element or performing a single saccade.

Sensitivity to high illumination levels and partial night blindness are among comorbidities of the INS, the other published issues actually being its consequences. The partial night blindness could correspond to the low responsivity of rods that has already been mentioned as a calcium channel issue. A more convincing argument is that the scene is too dark to provide interesting attention centers to initiate visual research, so no information about the scene may be collected. The sensitivity to (= irritability due) the high level of illumination arises because an excess amount of signal is collected for each gaze position prolonging the dwell time, upon pendular scanning. Therefore, too much voltage signal (frequency and intensity in a burst) is collected from a single scene element. This interpretation would lead into practical recommendation for a high contrast medium illumination-level environment for an INS individual.

5.2 The manifestations of the INS

INS features include its increase upon the fixation attempt, its dampening upon convergence, and the existence of null zones (one in contra-lateral direction for each eye) with decreased or even zero amplitude. The behavioral consequences of these characteristics are a decreased capacity for intentional fixation, preferential proximity to the target, development of preferential viewing direction in 3D space, blinking for eye refresh, squinting for paraxial vision, lack of confidence in his vision sense, and tendency to use hands to see, especially surfaces and textures. Preferential viewing direction also implies pointing the eyeballs in an off-axis direction with a compensatory behavior habit of tilting and rotating the head. The preferential head orientation may be found for each eyeball functional dominance in different and asymmetrical directions. These behaviors may easily be accommodated in a school setting, although in general teachers would first have to become informed about the syndrome.

The INS symptoms tend to be exacerbated under adverse psychological conditions. Likewise, it is challenging to create an environment where the stressors would not provoke the INS deterioration [3]. Recently, the psychological abuse and intimidation has started to be treated on par with the physical abuse. We hear of nystagmus becoming uncontrolled under extreme stress conditions to the degree that a vision in an eye becomes periodically blank. The INS individuals likely develop sensitivity to abusive psychological environments and respond adversely even after the stressors have been removed.

6 Functional vision of an INS individual

In summary, for an INS subject, the strategy of using saccades is secondary to the strategy to stabilize his gaze. The same muscles and nerves are used for both activities. For this reason, INS subjects opt not to use saccades, even in search. During the full pendulum cycle, an INS subject sees one element of the scene, while a normal individual sees a whole line of scene or makes a jump to a series of points of interest employing saccades. This means that an INS subject receives by a factor of about N less information about the world than a person with a normal vision, while his dwell time on a point increases. This also means that an INS subject functions in an about N times slower world. N depends on severity of INS.

During the full pendulum cycle, the information coincidentally collected in the peripheral field of vision is incomplete and unconsolidated. Therefore, during the effort of seeing, the INS subjects ignore non-central field information, meaning, that they do not perceive anything. While normal people see without exerting an effort, the INS subjects work at it. The INS subject would generally have a different corrective

prescription under the condition of relaxation from that at everyday functioning. For the INS subjects, seeing is work. The INS subjects use convergence to stabilize their eyeballs, but their two retinal images are formed with optical systems whose optical axes do not necessarily cross. Therefore, the INS subjects have no visual stereo vision. These individuals have a poor control over the 3D space, they will be observed searching with their hands for a near object. They know the world more by memory than by latest visual input, sometimes not seeing objects literally in front of their eyes.

Neither the people with the INS nor the people with the normal vision really understand how an INS subject sees the world. The eyeball moving in a pendular motion along the width of the eye (horizontal direction) detects the image in the same manner as a camera in a shaking hand: the image is blurred along the direction of motion. So, the INS subject moves the scene over the different photosensors. The area of the exposed photosensors on the retina has an elliptical shape. When an INS subject is examined for glasses, he is often prescribed a correction for astigmatism that is an aberration of an imaging system. Considering that the amplitude of oscillation varies, and that in many INS subjects it reduces to zero for optimal gaze direction, this apparent astigmatism should not be corrected.

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