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Multi-Sensory Factors When Examining Visual Fields in Unilateral Spatial Inattention and Its Effects on Treatment

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ABSTRACT

Unilateral spatial inattention (USI) is sometimes challenging to differentiate from true hemianopsia. Visual field testing can appear to be variable and inconsistent. The results of field testing may be conflicting depending on the method used. Factors to consider are the presentation method of targets, dual presentation, differences in target size, and other variables demanding increased attention. It is also important to examine the multi-sensory influence on the performance of the patient based on the neural pathways being utilized in each task. The following is a discussion of evaluation techniques of visual fields in patients who have suffered an acquired brain injury. Further, there will be a case example of an individual diagnosed with a right middle cerebral artery stroke and secondary visual field defect who presented with unique visual field results. Knowledge gained from comparison of these procedures may affect treatment. For example, a patient may show no signs of USI while sitting but exhibit USI when asked to stand. This individual may demonstrate visual field difficulties when attending to anything involving movement and balance. This unique aspect of processing of vision from a multi-sensory model can make treatment for such individuals more efficient, well-defined, and effective. This information will be essential for multi-disciplinary interactions to create better treatment strategies among rehabilitation disciplines. The procedures to be evaluated will be confrontation fields, static automated perimetry, and tangent screen fields under varied circumstances and test conditions to optimize treatment and to maximize performance of daily living activities.

Keywords: brain injury, evaluation techniques, rehabilitation, unilateral spatial inattention, visual field

Background

Visual information begins at the gathering of stimuli at the retina. This information comes down the optic nerve, and the information is sent to four areas of the brain: the lateral geniculate nucleus, the superior colliculus of the midbrain, the pretectum of the midbrain, and the suprachiasmatic nucleus of the hypothalamus. Information received by the superior colliculus is used in the control of eye movements. Information sent to the pretectum is used in pupillary reflex mechanisms. Information to the suprachiasmatic nucleus of the hypothalamus is used for diurnal rhythms and hormonal responses. Last, the majority of neural information is taken to the lateral geniculate nucleus (LGN) for visual perception.[1]

The LGN interprets visual information in segregated monocular form. It separates the information into three tracts of interpretation: magnocellular, parvocellular, and koniocellular. The magnocellular tract has large center/surround receptive fields, which detect movement. The parvocellular tract has small center/surround receptive fields, is sensitive to color, and discriminates shape, form, and contrast. The koniocellular tract has very small concentric receptive fields, which are very strong in detailed color discrimination. All of these LGN fibers travel along the optic radiations and terminate in the striate cortex.[1]

The striate cortex, also known as the primary visual cortex (V1), analyzes the data coming from the magnocellular, parvocellular, and koniocellular pathways, on/off receptive fields, directional orientation, ocular dominance, and directional dominance.[2] The koniocellular pathway is interpreted by V1 blob cells. These cells process information in a monocular process, determining color. They maintain the concentric receptive fields as in the LGN and are found in clusters. These cells also obtain information from parvo cells for color perception and discrimination and are responsible for the memory of object colors. A second type of cells in V1 are the interblob cells. These interpret binocular information via elongated rectangular receptive fields, which detect orientation and ocular dominance. These cells are clustered around the blob cells. Parvocellular information is interpreted here to understand object perception and discrimination, spatial orientation, form, and shape. Magnocellular information is interpreted with subsets of interblob cells, which detect motion, direction of motion, and velocity of object to guide in eye movements. If V1 is damaged, it causes complete blindness.[1]

After this visual information is interpreted in the striate cortex, it divides into areas of the extra-striate cortex for more detailed interpretation. Damage to any of these areas causes problems with visual information processing, such as issues with identifying color, shape, location, or motion.[1] These areas send information to the visual association cortex, located in the parietal and temporal lobes. Here, visual information is separated into the dorsal ("where") and ventral ("what") streams of information.

The dorsal stream is found in the parietal association cortex and the superior/middle temporal association cortex.

Information is interpreted in binocular receptive fields. Object location and movement help to determine spatial orientation, depth perception, and velocity of objects. Damage to this area causes deficits in spatial orientation, motion detection, and guidance in tracking eye movements.[1]

The ventral stream is located in the inferior temporal association cortex. This area is used in the recognition of objects and the ability to recognize and to interpret text (reading). Damage to this area causes issues in complex visual perception tasks that require attention and memory.[1] Although damage to V1 causes functional blindness, a secondary visual pathway composed of visual fibers to the pretectal nucleus of the superior colliculus creates a bypass of some 'visual' information. These fibers leave the pretectal nucleus and feed into the Edinger-Westphal nucleus and send connections to the frontal eye fields.[3] The frontal eye fields are responsible for saccadic function and react to motion. The lateral intraparietal area has also shown that it independently controls visual saccadic response and visual attention.[4] This motion processing can be observed in complete hemianopia and is hypothesized as the possible connection explaining the Riddoch phenomenon. This phenomenon occurs when motion is detected in an otherwise blind field.[5] Studies using fMRI comparing a patient with known V1 damage to controls have shown that this is from direct activation of V5, V3, and the parietal cortex, although the exact mechanism still is not well understood.[6] Research has demonstrated that if V1 is removed in monkey models, the animals continue to respond to orientation, shape, brightness, size, and motion of stimuli, but this disappears if the superior colliculus is destroyed. Functional imaging has shown that remaining activity is present in all of the extra-striate cortex and parts of the parietal lobe without the involvement of V1.[7] There have also been reports that there is direct subcortical input to V5, bypassing V1.[8] This supports the idea that the superior colliculus could be the link for "blind sight."

In the case of unilateral spatial inattention, it is not caused by problems with neurology of V1. Instead, it is a problem with attention processes. Attention is "the entire family of processes that mediate the choice of suitable mental or external events for consciousness and action."[9] Attention lies along a continuum of consciousness, which can be described as follows: arousal→ attention→ memory→ language→ praxis→ recognition→ visual-spatial recognition→ complex cognition. Bottom-up impairment includes issues with arousal and attention, which have a negative effect on the rest of the series.[9] Therefore, any damage to attention will also affect visual-spatial recognition, defined as "abilities involving visual processing skills, spatial awareness, self-object spatial relationships, visual spatial memory, and navigation of extra-personal space."[9] A disturbance in this spectrum causes unilateral spatial inattention. Characteristics of USI are deficits in "perceiving, attending, representing, and/or performing actions within" the left visual field.[10]

Defining which areas of the brain control attention is unclear. It is well accepted that USI is primarily a dysfunction of the parietal lobe, with issues also found from lesions in the cingulate gyrus, frontal eye fields, and brain stem.[11] Interestingly, USI only seems to manifest as an issue for right hemisphere lesions.[12] Experimentation on those with parietal lobe damage has shown that the process of engaging one object, releasing attention, and shifting to another object is controlled in the parietal lobe, and damage to this area causes neglect.[13] Agreement across neuropsychology demonstrates that cortico-subcortical fronto-parietal connections control spatial attention, and damage to these areas causes hemineglect in the contralateral field.[14] However, a study by Benson, et. al. has shown that this may not be the case. In a single case experiment with control, it was determined that USI was an imbalance in saccadic orienting, as well as a combination of

Table 1: Location of Cerebral Vascular Accidents in the Brain and Resulting Functional Defects

Major Artery Origin	Site of Cerebral Vascular Accident	Effect on Function
Internal Carotid Arteries	Anterior Cerebral Artery	Frontal lobe: possible USI, junctional defect, sector defect, superior defect, apraxia of gait, cerebral dementia, confused language
Internal Carotid Arteries	Left Middle Cerebral Artery	Hemianopsia, aphasia, apraxia, hemiplegia or hemiparesis, contralateral hypoesthesia, dysphagia
Internal Carotid Arteries	Right Middle Cerebral Artery	Hemianopsia, USI, prosopagnosia, hemiplegia or hemiparesis, contralateral hypoesthesia, dysphagia
Vertebro-Basilar Arteries	Posterior Cerebral Artery	Cortical blindness, alexia, visual agnosia, thalamic aphasia, ataxic (cerebellar) or flaccid (lower motor neuron) dysarthria
Circle of Willis	Anterior Communicating Arteries	Do not cause functional loss, can cause secondary flow issues due to other blocked arteries or incomplete circle (25% of population)

Table 2: Comparison of Visual Field Testing

Field Type	Positives	Negatives
Confrontation	Quick & Easy Picks up large defects (good for USI and hemianopsia) Can test static and kinetic	Does not detect small defects Background can affect testing (color of shirt, room)
Tangent Screen	Sensitive to small defects Accurate for brain localization	Time Only kinetic cues (arm, wand)
Automated Perimetry	Static Picks up small defects Computer analysis comparison to age normals	Can have tunneling (MIB effect) Kinetic programs not very good Poor accuracy in brain localization Defects are greater than they may actually be

Table 3: Results of Confrontation Visual Fields in Various Conditions

Condition	Static presentation of confrontation finger counting	Motion presentation of confrontation finger counting	Static dual presentation	Motion dual presentation	neck vibration/ vestibular input
Normal	Normal	Normal	Normal	Normal	Normal
Hemianopsia	Abnormal	Normal* or Abnormal	Normal* or Abnormal	Normal	No change
USI	Abnormal	Abnormal	Abnormal	Abnormal	Improved
Extinction	Normal	Normal	Abnormal	Abnormal	Improved

*Riddoch Phenomenon

inability to perceive information visually sampled and hyper-attention in the normal field.[15] This single case, however, is not significant enough to make any conclusions.

If an individual sustains an acquired brain injury, it is crucial to understand basic anatomy and how this affects the visual field so that it is easier to differentiate USI from true visual deficits. Based on the site of the brain injury, one can predict what visual outcome should occur. How a cerebral vascular accident affects vision can be seen in Table 1.[16]

Analysis of Visual Field Testing

There are many ways in which an individual's visual field can be tested, including confrontation, tangent screen, and automated perimetry (Tables 2 & 3). First, there are variables in target. In confrontations, one can use counting fingers, finger movement, or a confrontation wand. Variation in color is also used, commonly white or red targets. Counting fingers requires form recognition. Finger motion and confrontation wand are kinetic and incorporate motion detection, which could bypass V1 and be detected by extra-striate areas. This can be the case if the person is counting fingers and there is motion in presentation. In general, confrontation fields are completely unreliable for small defects and only find well-defined large defects.[17,18] Confrontation testing only seems to detect a defect about 38-50% of the time if it is not a defined defect such as an altitudinal defect or homonymous hemianopsia.[18,19] Regardless of this fact, it is still commonly used in vision care as a visual field screener. Because it does pick up large defects, such as hemianopsia and quadrantanopsia, it is perfectly acceptable as an initial test to identify a substantial loss.[20] This makes this test a quick, easy test for ABI patients and in visual neglect.

It has been cited that automated perimetry is more accurate in diagnosing neurological disease than kinetic perimetry, making static Humphrey perimetry the standard of care.[21] Humphrey specifically is more accurate than Matrix or FDT due to the fact that it is a solid flash of light as opposed to a frequency doubling image, which can induce a motion effect. It is more accurate because it will not activate motion sensing and bypass V1.[21] However, it is not as accurate in giving a true localization of the defect in the brain based on the field detected. A Humphrey visual field is more likely to show a more severe defect than is truly present compared to tangent screen fields and Goldmann perimetry.[22] Advantages are the precise repeatability of this testing method and the decrease in testing time. It also has the advantage of removing cues like a tangent rod.[23]

There are several issues with using the above-mentioned tests when dealing with determination of a unilateral spatial inattention vs. hemianopsia. Each element of discord is in relation to changes to attention based on the position of the individual, the task they are asked to perform, proprioceptive influences on performance, and various inter-related neurological issues. First, there is the question of the accuracy of the above-mentioned tests due to posture. If the patient is sitting, this is not a true gauge of how the person will perform during activities of daily living or when ambulatory in physical therapy and occupational therapy. When an individual stands, they must attend to balance, and cognitive abilities must now be split between visual awareness and balance. Since balance is tightly intertwined with peripheral vision, it is harder for someone to attend to visual stimuli when using vision for balance, making USI more pronounced. A study on the effects of a cell phone conversation on visual field using Goldmann visual fields demonstrates this well. The investigators tested normal individuals with and without visual complaints and compared their visual fields to ones performed while on a cell phone. There was a significant decrease in visual field when attending to a phone conversation.[24] When this idea is translated to visual field testing, it would be advantageous to have the patient both sit and stand while being tested for confrontation visual fields. During USI, one is likely to show differences, while with a hemianopsia, the loss would be constant. However, some patients may have visual field loss coupled with USI, making diagnosis difficult.

Another aspect that needs to be considered is the MIB effect (motion induced blindness). MIB causes extinction of peripherally viewed objects when simultaneously viewing a central fixation point when these peripheral targets are presented in a pattern that causes apparent motion. The suppression of microsaccades changes the gain in the visual system and causes disappearance of the peripheral targets. A study by Gorea and Caetta[25] showed that this extinction of peripheral objects is not isolated to the MIB effect alone. In their experiment, they also used static mask and absent mask targets to test the extinction phenomenon and how it varied under these three conditions. They found that although the MIB is a much stronger extinction of the peripheral object(s) being viewed, there was also temporary suppression found in the other two conditions. An example of a visual stimulus for MIB would be a central target and 3 targets in a triangular configuration surrounding the central point, with a grid rotating over the field. The grid is a moving mask, which causes the 3 paracentral points to disappear while fixating the central point. In static mask, the grid does not move. In absent mask, there is no grid. These latter 2 conditions would mimic an automated visual field because of the extent to which the patient has to hyper-focus on a central fixation target. In clinic, some patients will complain of tunneling or darkening of vision while trying to do a visual test, and they have to blink excessively to bring back their peripheral vision. They are experiencing this variant of the MIB effect. This may be why the extent of visual field severity is usually more pronounced in automated static perimetry than in tangent screen fields.

There are also variations that can be made in proprioception that can be positive in the detection of visual fields. According to Riddoch and Humphreys,[26] there is a distinction between extinction and unilateral spatial inattention. This distinction is important to understand, as this would change the results of testing. Often, these are considered to be one and the same. If a patient is presented with bilateral targets, and one is extinguished consistently on the left side, this is labeled left neglect (USI). However, when presented with a single target on the same side as visual extinction, they may actually see the target. Also, with USI, there does not have to be a competing stimulus for the individual not to see the stimulus presented in the neglected field. The difference is in the attending ability of the brain and possible different 'anatomical substrates.'[26] In visual extinction, the patient may or may not attend to an object based on the circumstance in which it is presented. It has been found that in patients with a brain lesion, if presented with objects oriented for action, the patient always saw the active object instead of the passive object regardless of location in space. However, if the same pictures were presented without showing action toward each other, the patient would pick up the picture on the ipsilateral side. When presented with two objects that were the same, they did not consistently extinguish the object on the contralateral side. An example was presentation of handled cups. If the handle was turned to the left (contralesional side), the patient was much more likely to attend to the object because it engaged motor planning on the left side. They also found that motor planning that required attention to the ipsilesional side and then disengagement to attend to the contralesional side showed performance benefit.[26] This is the complete opposite of USI, which has difficulty disengaging attention from the ipsilesional side.[13]

Patients with USI sometimes show signs of varied symptoms based on whether the targets are in peri-personal space (arm's reach) or extra-personal space. Patients who perform tests in peri-personal space can show neglect while having normal responses in extra-personal space.[27] However, when the person wields a tool, this makes that extra-personal space become part of the peri-personal space schema, and the neglect reappears.[28] The tool is detected as part of the body, which expands the peri-personal space. An example would be how an individual becomes aware of the extent of his or her vehicle on the road when driving. The car becomes part of the peri-personal space. Another example would be a baseball player knowing where the bat is in space when playing baseball. This evidence shows that neglect may not just be attention but an alteration of body schema. Maravita and colleagues suspect that wielding of tools relates to properties of intra-parietal neurons.[29] Considering that neglect comes from damage in the parietal lobe, this would coincide with the idea that if something is in the peri-personal space, it requires use of the parietal lobe and would exhibit neglect; however, outside this area would not be using damaged areas of the brain.[29] Bisley and Goldberg have found specifically that the medial intraparietal area responds to reaching, the anterior intraparietal area responds to grasping, and the lateral intraparietal area responds to eye movements.[4] Based on these ideas, treatment can then be manipulated to work on correcting body schema to increase awareness on the neglected side.

One method used to alter this body schema is neck vibration. Neck muscle vibrations stimulate alpha motor neurons, creating an illusion of head-on-trunk rotation to the side of the vibrations. This works by tricking the brain into thinking that the vibrations are lengthening or shortening the muscles.[30] Karnath and colleagues have demonstrated this to be an effective treatment.[31] They have also tested whether this effect would work with other areas of the body (e.g., left hand, head), but this did not have any effect.[30] These results were confirmed with later studies.[32] Rotation of the trunk 15 degrees to the left also showed improvement.[32] This changes egocentricity, correcting the neglect by altering the egocentric coordinate system used in 'visuomotor coordination and exploration of space.'[32] However, Roeden and colleagues found that neck vibration was not valuable in affecting visuo-spatial attention.[30] This is the same principle commonly used in prism adaptation treatments.[33] Use of base-left yoked prism, used in USI treatment, creates a directionally biased visuo-motor and sensory motor response.[10] Recently, it has been suggested that prism adaptation is a cerebello-cortical network response in spatial cognition.[34] Another tool for improving neglect is with vestibular input. Karnath[35] found that spatial neglect and vestibular processing at a cortical level involve common brain areas. Functional imaging studies have revealed the superior temporal cortex, the insulate, and the temporo-parietal junction to be important components of the multi-sensory system affected by neglect. With this in mind, clinics like Vision Northwest have also applied vestibular input to patient therapy programs. Karnath found that by using caloric vestibular stimulation, he was able to improve the neglect.[36] Vision Northwest has found similar improvements in patients with rotational vestibular stimulation. The patient is rotated 5-10 times to the left on a rotational chair. This provides a

Table 4: Case Example--Progression of Results Over Time

Visit	Static Confrontation Finger Counting	Kinetic Confrontation Finger Counting	Dual Presentation (static and motion unless otherwise indicated)	Full Threshold Visual Field (Automated)
Sept 2012	-------------	-------------		OD & OS complete left hemianopsia with enlarged blind spot and decreased detection in the right field
Oct 2012	Left defect	Normal	Left extinction (static & motion count fingers): No improvement with cervical stimulation Then, had patient hold out own hands and be aware of them—she sees them both. Self-present dual targets: no extinction no effect with neck vibration	Incongruous left hemianopsia
Dec 2012	-------------	-------------		OD: left hemianopsia OS: left inferior quadrantanopsia
Feb 2013	Left defect	Normal	Left extinction (static & motion count fingers) Had patient throw beanbags up in each hand simultaneously Post-beanbag: no extinction Added turn-and-clap therapy	OD: left hemianopsia OS: left inferior quadrantanopsia
March 2013	Left defect	Normal	Left extinction (static count fingers) Static right target/kinetic left target, count fingers: no extinction	

Figure 1A

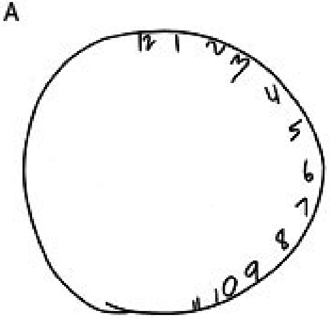

Figure 1B

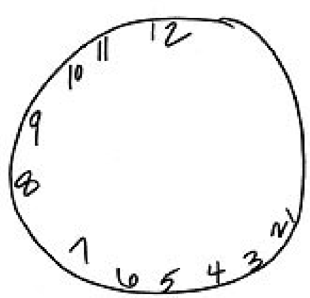

Figure 1. Comparison of Draw-A-Clock Test when starting clockwise vs. counterclockwise. *The images shown were drawn on the same day by the same individual. This individual experienced a massive Right ICH secondary to HTN (X 10 yrs). Note, this is not patient example. This figure demonstrates how the draw-a-clock test is not really a test of neglect, but rather a test of hemisphere communication in general. It shows that this particular patient, if only dependent on results from Figure 1A, would be diagnosed with USI. However, when asked to repeat the process drawing counterclockwise, the patient did not draw the numbers in a fashion that neglected the left visual field, as shown in Figure 1B. This patient cannot attend to sequencing and spacing simultaneously.*

post-rotary nystagmus to the left and an increase in attention to the left visual space. Experimentation with these principles is demonstrated in case example 1, below. Rotational vestibular, cervical, and bi-hemispheric activities need further investigation via formal study.

Case Example

The case example is an 80-year-old female who suffered a middle cerebral artery CVA in the M2 branch in July 2012 and was given tissue plasminogen activator (tPA) to improve her outcomes. This patient was unaware of her neglect. She was tested for simultagnosia, which was negative. After receiving therapy, she was cleared in March 2013 by the rehabilitative service for driving, and the examiner (an occupational therapist) noted no signs of left neglect. Table 4 shows a review of her progress and the therapies performed. Treatment at Vision Northwest began in October 2012.

As exemplified in the case given, a patient may show neglect initially in a static and kinetic presentation. However, as attention improves, kinetic fields generally improve before static fields. Since real-world situations are rarely static, it suggests that she would be safe to drive because all targets would be either moving or have a motion parallax effect when in a moving vehicle. Therefore, Humphrey visual fields don't truly measure how this patient is functioning. It is important, however, to have these patients examined by an occupational therapist for driving rehabilitative services because they investigate additional aspects of these tasks.

Discussion

We have found that patients respond best by using cervical and/or vestibular input, followed immediately by increased spatial awareness activities, especially tasks that are multisensory and bi-hemispheric in nature. An example would be using a pencil and drawing a clock with appropriate numbers in order. The patient is required to recall the number sequences (left hemisphere function) with the spatial distribution on the clock (right hemisphere function). Figure 1A shows a typical left neglect response with the numbers primarily on the right side from a patient who suffered a right middle cerebral artery stroke. When the patient is asked to draw the numbers in reverse order from 12 to 1, he has then shifted well to the left side (Figure 1B) because he is unable to alternate his attention between right and left hemispheres.[37] In this case of right hemisphere brain damage, the patient dominantly attends with the left hemisphere. The patient cannot attend alternately to both spatial awareness (right hemisphere) and sequencing (left hemisphere). As recovery improves, the patient is able to increase right hemispheric processing (spatial distribution of numbers) and draws the clock better.

Taking the above-mentioned principles into account, this alters the way one would view the application of visual fields in the diagnosis and treatment of those with a suspected USI vs. hemianopsia, as well as influences the treatment. The easiest means to diagnose an individual with ABI for these conditions is using confrontation visual fields with a vibration device. This is easy, requires no equipment that cannot be easily transferred, and is therefore hospital-friendly.

Conclusion

Testing of visual fields and USI can be done by confrontation, tangent screen, and threshold testing. This can be used with imaging to develop a good understanding of the type of loss (i.e., hemianopsia/quadrantanopsia vs. USI). Each test has different demands that need to be shared with the multidisciplinary team. An important consideration is testing for USI while standing compared to sitting. Confrontation fields counting fingers should include both static and kinetic presentation. Testing can also include variable probes, including (A) standing vs. sitting, (B) cervical stimulation, (C) vestibular stimulation, and (D) peri-personal vs. extra-personal space. The use of the above probes, integrated with traditional USI therapy, should help speed the recovery and overall outcomes of USI. The use of these probes with the multidisciplinary team may provide a process of rehabilitation and treatment that is more efficacious to improving a variety of different daily living activities.

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