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Rehabilitation of visual processing deficits following brain injury

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Abstract

Visual processing deficits are a common sequelae in individuals who have sustained a brain injury. Visual processing includes the acquisition of visual information and the appropriate use and manipulation of that information based upon task or environmental demands. Following brain injury, visual processing deficits can manifest in various ways, and will likely interfere with the patient's progress and rehabilitation outcome. This article describes the importance of understanding and accurately identifying visual processing deficits and implementing specific rehabilitation strategies to maximize functional independence.

Keywords: Visual Processing; Brain injury; Neurorehabilitation

1. Introduction

Vision is the most important sensory system that humans use to obtain information about the surrounding environment. The visual system consists of the eyeball, the optic nerve and several areas of the brain, which interact in complex ways that are currently only partially understood. Many people use the term 'visual perception' to describe how the visual system operates, although the actual process of visual perception enables us to 'make sense of' information processed by this sensory system.

There are a large number of identifiable visual processing skills operating within the visual system, and there have been several attempts to describe them in some kind of rational framework. These include the Deficit Skill Approach, which categorizes visual processing into specific deficits, and the Information Processing Models [1], which describe the reception, organization and assimilation of visual information on a continuum from simple to complex. An example of the latter is found in the work of Warren [2,3] who appears to have provided the best approach

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toward understanding visual processing. In her model, each skill level is dependent upon the skill level below it, and relies on the following functions: including visual cognition, visual memory, pattern recognition, scanning and visual attention. These functions can be described as follows:

Visual cognition: The ability to mentally manipulate visual information and integrate it with other sensory information to solve problems, formulate plans and make decisions. It includes the ability to analyze similarities and differences, to understand the relationship of stimulus elements to one another, and to reason and deduce about the nature of visual stimuli. It also includes the ability to use contextual cues to help in the development of meaning from the image.

Visual memory: The ability to visually process stimuli, store them in memory and retrieve them upon command. The individual must also be able to match what they see with what is stored in memory.

Pattern recognition: The ability to identify the salient features of an object including configural and holistic aspects such as shape, contour, and general features as well as specific features of a stimulus, such as color, details, shading, and texture. It is important for the individual to be able to recognize objects even when viewed from different or obscure angles (perceptual constancy).

Scanning: The ability to record all details of a scene systematically in an organized and thorough manner. The route taken is known as the scan path [4]. The eyes obtain and process information by executing a series of broad sweeping cycles with reexamination of the most important details several times to ensure identification. These eye movements are known as saccades. Saccadic eye movements are normally executed in an organized, systematic, and efficient pattern [5–7].

Visual attention: The ability to attend to stimuli and shift attention between stimuli [7].

The above cited functions are primarily related to two visual processes; focal and ambient. As defined by Trevarthen and Sperry [8] the focal process constitutes detailed discrimination related to attention and concentration, whereas the ambient process invokes spatial-orientation and detection of movements and balance. When these processes are intact and working properly they will facilitate information processing with cognitive functions such as spatial reasoning, visual memory and perceptual constancy.

These visual functions are in turn dependent on three factors including:

- Oculomotor control — ability to move the eyes. This enables the eyes to work together, known as conjugate eye movements, and ensures the scan path is quickly and accurately completed. Binocular vision, stereopsis, accommodation, convergence, motilities and fusion of images are all subsumed under this basic skill area.
- Visual fields — the area which the eyes can see at any one time. These register the visual scene and affect the quantity of information taken in by the individual.
- Visual acuity — the sharpness of the eyesight. This ensures that visual information sent to the brain is accurate. It affects the quality of the information taken in by the individual.

2. Disorders of visual processing

Damage to the eye itself, the optic nerve and chiasm, the cranial nerves, or to the midbrain and cortical structures, can all lead to disorders of visual processing [9–11]. Indeed most visual processing deficits occur in the foundation skills of visual acuity, visual fields and oculomotor control, and those dependent on these abilities: visual scanning and visual attention [2].

2.1. Symptoms of visual acuity

These disorders may result in essential features of objects being missed [12]. Near and far sightedness are examples of problems in this area. Headaches are a common complaint or symptom associated with altered visual acuity.

2.2. Symptoms of visual fields

Visual field problems can be described as total losses, sector losses, central losses, peripheral losses, congruous and incongruous homonymous defects and altitudinal losses [13]. Gianutsos and Matheson [14] offer some guidance for distinguishing between two types of field loss which they report are common among individuals who have sustained a brain injury, as follows:

- peripheral field problems, involving hemi-imperception and unilateral spatial neglect. This typically manifests with difficulties in visual processing (reading, scanning) and adversely affects the visual fields contralateral to the lesion site. For example, a right posterior hemisphere lesion (temporal lobe) may result in a left visual field deficit.
- central field problems, involving hemi-imperception. This typically manifests with difficulties in visual processing (reading) and interferes with reading the beginning and end of words presented centrally.

Diller and Weinberg [15] believe that visual field problems are the primary deficit underlying all problems of visual processing following right hemisphere involvement.

2.3. Symptoms of oculomotor control

Symptoms often associated with oculomotor problems include:

- double vision;
- eye strain and/or pain;
- reduced depth perception;
- inability to focus easily between targets;
- inability of the eyes to engage in simultaneous, coordinated tracking movements (conjugate eye movements);
- accommodative dysfunction;
- nystagmus; and
- convergence insufficiency.

2.4. Symptoms of visual attention

Two types of visual attention disorders include:

- Preattentive vision, which is ambient, instantaneous, effortless and expansive; and
- Attentive vision, which involves serial processing and effortful scanning.

Following brain injury visual disturbances tend to occur in attentive vision, whereas preattentive vision remains grossly intact [16,17]. Thus, brain injured individuals can adequately scan tasks which are highly structured or require only simple discrimination, but have difficulty when the task complexity or demands increase [18]. The most commonly reported symptoms include [16,17,19,20]:

- inability to attend to critical features and variables;
- difficulty in sustaining gaze on specific objects or features;
- inability to organize unstructured information;
- poor attention/concentration; and
- staring behavior.

In addition, difficulty in shifting attention, or in absorbing more than one aspect of information at a time, may be due to slowness in assimilating and decoding information [12].

2.5. Symptoms of visual scanning

These disorders are often observed when there is difficulty in reading lines of print but without difficulty when single words are presented centrally. The eye movements of the brain injured individual may be erratic and thus fail to identify the critical elements. Most normal (non-brain injured) individuals use a circular clockwise or counter clockwise scanning pattern, usually beginning in the upper left quadrant. After brain injury, people tend to be slower, fixate longer, show irregular and unsystematic search patterns and demonstrate less accuracy of locating targets [5]. Saccadic deficits include the following [3,12,18]:

- failure to initiate saccades towards the field contralateral to side of the lesion;
- increased delay in starting saccades towards the field contralateral to the lesion site;
- decreased saccadic accuracy in the affected visual field;

- inability to fixate gaze in contralateral field;
- tendency to fixate first on the most peripheral visual stimuli in the unaffected visual field;
- tendency to be distracted by peripherally occurring stimuli in the unaffected visual field;
- overfixation on one portion of an object;
- halting scanning pattern;
- decreased effort in scanning and extracting essential features of objects; and
- gross disturbances in left to right scanning.

2.6. *Symptoms of higher level visual processing*

Disorders of visual cognition and higher level visual processing result in difficulties in the identification of the spatial properties of objects and the mental manipulation of these in thought. They include the following:

- impaired visual analysis and synthesis — failure to perceive foreground from background;
- impaired localization of objects in relation to self in space, including defective judgement;
- impaired judgement of direction and distance, spatial positioning of objects and depth perception;
- impaired facial recognition (Prosopagnosia);
- failure to recognize objects even though vision is still intact (Visual object agnosia);
- body image disturbances.

Moreover, there is also a potential for the brain injured individual to have difficulties in perceiving movement even when all other visual functions remain intact. This is due to the brain's organizational structure whereby different brain regions control this aspect of visual processing [14].

In fact, so specific and common are these visual processing problems that Padula, Argyris and Ray [21] describe a Post-Trauma Vision Syndrome (PTVS), which is exclusive to individuals who have suffered a neurological insult. The following are the most common problems:

- exotropia or high exophoria;
- accommodative dysfunction;
- convergence insufficiency;
- low blink rate;
- spatial disorientation;
- poor fixation;
- irregular eye pursuit movements when tracking an object visually; and
- unstable ambient vision.

The aforementioned problems are characteristics and not the cause of PTVS. Research suggests that this is a dysfunction of ambient vision which renders the individual without ambient or spatial reference [21].

The impact of these visual processing problems is compounded by the fact that many brain injured individuals are not aware of these problems, particularly when partial losses are evidenced [22,23]. This limited self-awareness causes a complication in determining the incidence and nature of visual processing deficits after brain injury. Thus, visual processing deficits may go undetected as they are not always obvious to the observer, and patients are often unable to appreciate or describe the difficulty they are having. In addition, the patient is unlikely to spontaneously try to compensate for her/his visual processing problems since they possess minimal or no awareness of their existence [23]. If the patient does not report visual processing problems (or if they are not asked about this difficulty), they may not be evaluated and therefore may go unnoticed. This issue of awareness/unawareness of these deficits is one of prime therapeutic importance and early identification will undoubtedly increase the individual's awareness and positive rehabilitation outcome.

3. Visual processing following brain injury

Vision is our most important source for interacting with our environment; it plays a critical role in all activities of daily living (ADL'S). This observation underscores the importance of the finding that a majority of individuals who experience traumatic brain injury suffer from visual processing problems. This has been demonstrated in a number of research investigations, and major findings from these studies are as follows:

- Gianutsos et al. [23] reported that 50–65% of severely brain injured individuals had visual processing problems which required further professional exploration by an optometrist/opthalmologist. The majority of these patients required non-routine types of intervention, many having combinations of visual processing problems which were further compounded by confusion and reduced cognitive function;
- Cohen et al. [10] reported that vergence difficulties were evident in 38% of acute traumatic brain injured individuals. In addition they found that in a 3-year follow-up 42% of patients had vergence insufficiencies;
- Mitchell, MacFarlane and Cornell [24] reported that 79% of brain injured individuals had strabismus, with the most common problem reported as diplopia;
- Sarno and Sarno [25] reported that 20% of all stroke patients in their study suffered from some form of visual problem;
- Schlageter, Gray, Hall, Shaw and Sammet [26] reported that 59% of the brain injured individuals in their study displayed visual problems;
- Adams and Hurwitz [27] reported that 60% of stroke patients had unilateral neglect; and
- Feigenson, McCarthy, Greenberg and Feigenson [28] reported that 20% of all individuals admitted to a rehabilitation center had perceptual problems and that these were clearly associated with increased length of stay in the hospital and an adverse effect on discharge and subsequent placement.

It is important to deal with these visual processing problems since without accurate perception of the environment, the individual is unable to make clear and effective sense of what is happening. In addition, visual processing problems have been shown to be associated with poor performance in reading, accident proneness and dependence in self-care activities after cerebrovascular accidents (CVA's) [3].

It appears that cognitive deficits are worse when visual processing problems are not identified or treated, [29]. Thus, it is essential to have an effective, integrated and compensated visual system in order to enhance the potential for cognitive improvements in individuals who have sustained a brain injury, [11].

As with most brain functions, many areas of the brain are involved in visual processing. Visual processing is normally associated with the occipital lobes, which are generally regarded as the primary and secondary regions of the visual cortex. Higher level visual processing involved in cross-modality analysis and facial recognition involves regions of the parietal, temporal, and even the frontal lobes. There is an alternative visual system as well, mediated through the upper brainstem structures, most notably the superior colliculus which appears to be sensitive to movement and gross shapes with low spatial frequencies. This system is important in spatial orientation, visual tracking, eye movements, fusion and localization of objects. The lateral geniculate nuclei, which are involved in coding color information, actually receive a majority of the optic nerve projections in humans, and from there, information is relayed to the cortex.

Sohlberg and Mateer [30] proposed a model of visual processing incorporating the functions of all five of the major areas of the brain:

- Peripheral and Brainstem mechanisms — are responsible for visual acuity/clarity of vision, coordination of the eyes and eye movement. Upper Brainstem and Mid Brain mechanisms — are responsible for a second visual system which provides information to the brain about the location and movement of objects in space. It is also concerned with noticing and locating objects and shifting gaze, but not for recognition. These areas do not appear to be accessible to conscious awareness.
- Occipital lobes — are responsible for analysis of visual information incorporating the perception of visual detail and color;

- Temporal lobes — are responsible for object and facial recognition based on experience and memory;
- Parietal lobes — are responsible for awareness of where things are in space and how to coordinate movements to touch or avoid them; and
- Frontal lobes — are responsible for high level planning of movements in relation to spatial positions of objects and some aspects of visual memory.

4. Assessment and rehabilitation of visual processing deficits

4.1 Assessment

The assessment of visual processing is initially completed as part of a medical history and physical (HP), or during a formal neurological and/or neuropsychological examination. This 'gross' assessment may detect problems with visual processing which would warrant additional evaluation by an opthalmologist or optometrist. Preferably, a neuro-optometric rehabilitation consultation will be suggested. Gianutsos et al. [23] recommend that all patients who experience any degree of problem on their computerized assessments of Speeded Reading Word Lists and Single And Double Simultaneous Presentation (two easily administered screening tests) [31] should be referred to a behavioral or neuro-optometrist. It was also noted that referrals made to opthalmologists may be insufficient since they are primarily concerned with the physiologic health of the eye only, and opthalmologists are mostly experienced with acute medical problems rather than rehabilitation issues. This assertion is supported by considering the typical components of an opthalmologic exam, which may yield a lack of specificity, and/or provide information which is inadequately defined in terms of rehabilitation consequence. Trobe, Acosta, Krischer and Trick [32] identify a lack of functional measurement in areas of distance and near acuities, contrast sensitivity and confrontation, while Gianutsos and Matheson [14] describe a need for greater quantification in terms of field gradations and boundaries, and binocularity conditions. A more thorough investigation is important for the rehabilitative efforts of all patients who demonstrate visual processing deficits.

The following should be included in the assessment of visual processing:

4.1.1. Interview

Visual processing assessment should begin with a formal interview with the patient and/or family regarding visual (medical) history. For instance, orbital fractures can lead to reduced range of motion of the eyes or diplopia, and direct eye trauma can lead to optic atrophy, retinal detachment, cataracts, glaucoma or corneal scarring. As part of this interview, a subjective vision questionnaire could be developed and used, in order to ascertain the impact on daily function and self-awareness of visual processing problems.

4.1.2. Visual assessment

Each of the visual areas should be assessed:

- *Visual field.* These can be assessed using confrontation but due to its insensitivity it should only be used as a screening device. Careful observation of the person in daily activities, including reading, can yield useful information. The computerized REACT test [33] can be used particularly with one eye at a time fixed on the central point. Perimetry produces a printout pattern of the visual problems, but this requires expensive equipment and well-trained staff;
- *Visual acuity.* Contrast sensitivity function testing is useful here. Acuity should be measured in each eye and for both near and far points [14]. Again this procedure requires equipment and trained staff; and
- *Oculomotor function.* Binocular incapacities should be measured, including diplopia, accommodation and suppression problems [14]. A simple screen technique (eye observation) can be used by therapists.

This should address the following questions:

- Do the eyes move smoothly? Ask the patient to track a target moved in a circular motion;
- Do the eyes move in all directions? Ask the patient to track around a letter H with each eye in turn;
- Can the eyes sustain a fixation? Ask the patient to sustain his/her gaze on an object for 9 s with each eye;
- Do the eyes converge on a near stimulus? Ask the patient to look at a target brought slowly towards their face;
- *Visual attention and scanning*. These are often tested together since they are difficult to separate in practice. Letter cancellation and bisection tests are particularly sensitive to these functions. Single letter cross out tests and alternate cross out tests can be used (asking the patient to cross out first one letter and then another, or asking the patient to cross out two different letters). The latter provides a more complex task demand. The reading and arithmetic sections from the WRAT-3 can be used. Copying an address and the WAIS-R Digit Span — backward [34] are also useful — the latter requiring internal visual scanning. Less structured tests should also be considered, such as the REACT computerized test. Tests should include pursuits (tested by asking the patient to follow a moving penlight) and saccades (tested by asking the patient to change fixation between two targets), [1]; and
- Pattern recognition, visual memory and visual cognition. Ravens Progressive Colored Matrices [35] and the WAIS-R Block Design subtest provide useful information for this level of skill function. There should be minimal emphasis on scores and much more on how the person approaches the tasks and which types of cues provide the greatest benefit toward performance. Visual sequential memory, visual spatial relations and visual figure ground are all skills which should be examined in this section [1].

Toglia [12] discusses the need to examine visual processing at varying levels of task demand since visual problems become most evident under timed conditions [36,37]. It is therefore important to use dynamic tasks as part of the assessment process. For example, the use of speeded computer tasks is recommended [14]. Toglia [12] suggests the following components in this process, with details of increased demands for each component:

- Environment. Tasks can be presented in a normal context, in an associated context and out of context;
- Familiarity. Tasks can be self related, non-self related or unconventional;
- Directions from another person. These can be very directive i.e. 'What is this?', can be less directive, i.e. 'Find the object', or non-directive i.e. 'Tell me what you see';
- The amount of objects presented at any one time can be manipulated from 1 to 20;
- Spatial arrangements can be manipulated to be linear non-rotated, scattered rotated or scattered, rotated and overlapping; and
- The response rate can be altered from 1.3 s to 1.1 s– < 0.8 s.

Padula [38] addresses the importance of a neuro-optometric rehabilitation evaluation prior to commencing rehabilitation. Results of this evaluation will serve as a guideline for future treatments including lense prisms or multi-disciplinary interventions.

4.2. Rehabilitation

The rehabilitation of visual processing deficits begins once the visual assessment is completed and specific deficits are identified. As previously noted, treatment can be multi-disciplinary and be provided by a variety of professionals including optometrists, neuropsychologists, and vision, cognitive and occupational therapists.

As with other areas of cognitive rehabilitation, there are two broad approaches to the treatment of visual processing deficits, adaptive and remedial, [39]. Utilizing these approaches in combination may result in the most successful rehabilitation outcome [2]. *Adaptive* treatment is provided in activities of daily living (ADL's).

This approach assumes the following:

- the adult brain has limited potential to repair and reorganize itself after brain injury;
- intact behaviors can be used to compensate for impaired ones;
- adaptive retraining can facilitate the substitution of intact behaviors for impaired ones;
- adaptive activities of daily living provide training in functional behaviors;
- training in specific ADL tasks is necessary due to generalization problems;
- functional activities require perceptual abilities; and
- perceptual adaptation will improve functional performance [39].

Remedial treatment is to promote recovery or reorganization of impaired brain function.

This approach assumes the following:

- the adult brain can repair or reorganize itself after brain injury;
- this repair and reorganization is influenced by environmental stimulation;
- perceptual and sensorimotor exercises can promote brain recovery and reorganization;
- perceptual and sensorimotor exercises provide training in the perceptual skills needed for those exercises;
- remedial training in visual perception will be generalized across all activities requiring those perceptual skills;
- functional activities require perceptual abilities; and
- perceptual remediation will improve functional performance [39].

4.1.2. Stages in the treatment and rehabilitation of visual processing dysfunction

Stage I: Treatment should begin with an initial diagnostic evaluation, since effective treatment planning requires understanding of the underlying reasons for the deficit, as well as delineation of the conditions that influence performance [12]. This initial evaluation should be completed by a neurobehavioral optometrist, or cognitive, occupational or vision therapist.

Stage II: Treatment can then aim to minimize the sensory deficit by introducing assistive devices such as eyeglasses, prisms, patching, telephones with large numbers, increased illumination, large print books, and magnifiers [13,2], or through corrective surgery [26].

Stage III: Treatment can then proceed with an educational component with the aim of teaching the client about visual processing areas [26]. This is important since without good awareness of problems the client will not be motivated to try to overcome them. This can be done by providing immediate feedback whenever problems occur and through teaching self monitoring techniques [2].

Stage IV: Treatment can then proceed with exercise and retraining activities with repeated practice, in order to increase function. This training should be consistent and systematic and can be based on training exercises (visual processing skills retraining) or on daily living tasks (functional approach). The former is concerned with treating the cause whereas the latter is more concerned with treating the symptom. For example, a client who has trouble making coffee due to problems with spatial awareness and visual perception can, through extensive repetition, have a routine established with cues to compensate for his or her problem. These routines are then practiced until the client is able to make the coffee independently. He or she still has the spatial and visual perceptual problems but becomes independent in that particular task.

Practice on training tasks is used by many professionals involved in rehabilitation. This approach is based on the assumption that training of specific activities will either improve the brain's ability to do these tasks (the 'mental muscle model') or the residual mental functions that have escaped damage will take over the damaged areas/functions (the classic Lurian approach). This approach should also include specific instructions for compensatory strategies, [40].

Throughout this fourth stage of treatment and rehabilitation, there is a need to address visual field, acuity and oculomotor control functions since they form the foundation for all higher visual processing [3]. There is a generally held view that visual field deficits are untreatable, but Gianutsos and Matheson [14] report that the contour of the visual field deficit relates to the ability to compensate for the losses. If it is abrupt (the boundary between seeing and non-seeing is sudden), spontaneous compensation is unlikely, but if it is gradual, then some compensation can occur. Performance can be improved despite no changes in acuity or visual field. The use of field prisms have demonstrated improvements in individuals with homonymous hemianopsia, while yoked prisms have demonstrated similar improvements in those individuals with visual midline shift syndrome (VMSS).

Stage V: The final stage is to actively promote compensation and self-management strategies so that the client can predict situations of potential difficulty and adjust her/his behavior accordingly [12,14]. In particular, it should be noted that generalization needs to be planned for by practicing each skill in real life contexts as well as using a variety of clinical tasks [2,18].

There are two broad types of strategies: Self monitoring strategies are effective in many tasks. Examples of these include anticipation, checking outcomes, prediction of problems, pacing (e.g. by asking patients to name each letter or word when reading) and stimulus reduction (e.g. covering text which is not being viewed or by increasing the size of letters and the gaps between them). Situational strategies are effective only in selected tasks, including visual scanning, visual imagery, emphasizing conscious attention to detail, visual analysis, anchoring cues used to draw attention to the left visual field and broadening the visual field by requiring the client to turn his/her head or change body position to complete the task [17,41,42].

5. Efficacy studies

A number of studies have demonstrated the effectiveness of treatment and rehabilitation for visual processing deficits, and findings from these studies can be summarized as follows:

- Diller and Weinberg, [15] reported that training of visual scanning reduced neglect in right brain damaged stroke patients. A further study [42] found that a program that incorporated the treatment of organization of spatial and sensory cues into the visual scanning program was more effective than one dealing with visual scanning training alone. The problems were ameliorated by making the patient aware that the deficit existed and by encouraging the use of visual cues to assist in exploring one's environment.
- Gianutsos and Matheson [14] reported a review of five studies involving approximately 150 treated patients. Four of the five studies found consistent beneficial effects of visual processing skills training for the patients which were over and above improvements resulting from conventional therapy [18,41–44].
- Warren [3] reported specifically on the effects of visual processing training on improving visual field deficits. She stated that although results are controversial, there is research which indicates the possibility of reducing the size of the visual field problem by appropriate stimulation of the blind hemifield [45–51]. She also concluded that training can be effective in increasing a person's ability to compensate for a visual field deficit [14,52].
- Research conducted by Schlageter et al. [26] indicated that visual processing therapy may improve visual performance.
- Cohen and Soden [13] reported that by modifying classic vision therapy techniques, as well as adding new procedures specifically designed for these patients, visual rehabilitation of stroke victims can successfully be accomplished.
- Weinberg et al. [42] reported that gains in visual processing made through therapy were maintained a year after discharge, and generalization to other tasks was good.
- Padula et al. [21] recognized that binocular problems are often only a representation of the imbalance in focal/ambient processing

and treatment to bring these processes into balance can often demonstrate immediate performance improvements.

6. Conclusion

It is well documented that visual processing deficits are a common problem following brain injury. The impact of these deficits is likely compounded by associated or coexisting problems and cognitive, behavioral, psychological and medical conditions. Proper and comprehensive visual assessment is vital in identifying potential visual deficits. Once these deficits have been identified, the implementation of visual (cognitive) rehabilitation strategies can occur. Undoubtedly, effective treatment and rehabilitation for visual processing deficits will result in improved functional adaptation, better rehabilitation outcomes and a more favorable prognosis.

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