

From the DEPARTMENT OF CLINICAL SCIENCES  
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# **THE NECESSITY TO CONSIDER VISUAL DYSFUNCTIONS AFTER ACQUIRED BRAIN INJURY**

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**Karolinska  
Institutet**

Stockholm 2021

PREVIEW

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Published by Karolinska Institutet.

Printed by Universitetsservice US-AB, 2021

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ISBN 978-91-8016-134-3

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# THESIS FOR DOCTORAL DEGREE (PhD)

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The thesis will be defended in public at Danderyds Hospital, Stockholm, hus 18 (målpunkt J) plan 5, föreläsningssal Venen, 12 March 2021, 10.00.

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PREVIEW



To my four-leaf clover:

To my patients for teaching me perspectives of life

To my team at Huddinge for support and comradeship

To Inger Grönberg for always being there

And to my husband, Claes-Henric Berthold, for love.

# POPULAR SCIENCE SUMMARY OF THE THESIS

The brain receives its information concerning the outside world from our senses: vision, hearing, smell, taste and sensation. Vision is the dominant sense in man and the basis for important functions such as reading, avoiding obstacles, detecting danger, or being able to drive a car or ride a bicycle. Both directing the gaze and interpret visual information are complicated processes involving widespread networks in the brain, and thereby easily injured in connection with an acquired brain injury, ABI. The impact of an ABI can be divided into damage directly to the flow of visual information, such as loss of visual field or glare, or damage to the eye motor system, making it difficult to direct the gaze. This doctoral dissertation has focused on detecting and defining different types of visual deficits after an ABI, as well as evaluate vision rehabilitation. The patients who participated had suffered moderate to severe ABI, in most cases caused by stroke, and were 18-67 years old.

In the first study 170 patients responded to a structured interview intended to define whether there was a visual impact and, if so, the type of symptom. More than half of the patients experienced a change in vision. This result was consistent with other studies. The most common problems were the effect on reading, 53%, glare, 35%, and blurred vision, 35%. One tenth of the patients did not experience any change in vision but answered yes to 4–9 of the questions about visual symptoms. It seems that sometimes it is difficult to determine whether a problem is due to changes in vision or not. However, if the patients are posed more specific questions about their situation, the difficulties are revealed.

In the second study 123 patients were examined concerning if increased vision problems were associated with other common and severe symptoms after an ABI such as fatigue, anxiety and depression. The study revealed a correlation between medium to severe fatigue and increasing visual problems, but no such correlation was found with anxiety or depression.

In the third study 73 patients were interviewed concerning visual changes and were examined by an optometrist. Both types of assessments showed high levels of vision deficits in accordance with the first study. The most common oculomotor deficits found were problems in adjusting the gaze or shifting a clear and steady gaze between near and far. These symptoms are difficult to diagnose in a regular medical examination. Thus, a vision specialist examination is needed. The conclusion of the study was that both subjective and objective assessments are required for a good quality vision examination.

In the fourth study 48 patients with ABI received visual rehabilitation and, compared to a control group with 41 patients, there was a statistically significant improvement in vergence abilities. The control group also showed some improvement, but except for fusion at distance, the changes was not statistically significant.

## ABSTRACT

Visual information is processed in wide and extensive networks in the brain, and forms part of executive functions, emotions and memories. An acquired brain injury (ABI) often brings about a disruption of these networks and around half of the patients develop visual dysfunctions. Due to these injuries, patients may have a diminished ability to handle an environment full of impressions, to react quickly to danger, or they develop impaired reading-social- or working abilities. Despite these common effects, visual dysfunctions have not been central in neurorehabilitation. The purpose of this thesis was to examine the occurrence of visual dysfunctions after ABI as well as evaluate vision therapy and discuss its effect on neurorehabilitation. All patients included in the studies suffered from medium to severe ABI.

In study I the frequency and type of visual deficits were examined. In study II visual dysfunction and their association with fatigue, anxiety or depression were examined. In study III, two different types of subjective and one objective assessment of visual dysfunctions were undertaken in order to evaluate if these assessments correlated or supplemented each other. In study IV the effect of vision therapy (VT) of vergence dysfunctions was examined.

*Results:* In study I, the answers of 170 patients to a questionnaire, Visual Interview (VI), revealed that half of the patients experienced visual changes, mostly reading disorder (53 %), followed by blurred vision and glare (both symptoms 35%). A fourth of the patients had visual field disorders and a fifth suffered from double vision. Two-tenths of the patients, who did not experience any vision change, answered “yes” 4–9 times to specific questions concerning visual dysfunctions.

In study II, with 123 patients included, an association between increased visual dysfunctions and medium to severe fatigue was found. However, there was no such correlation found between increased visual dysfunctions and anxiety or depression.

In study III 73 patients answered two questionnaires, VI, and Convergence Insufficiency Symptom Survey (CISS) and underwent a visual examination. All three assessments showed high scores of visual dysfunctions. VI and the visual examination correlated to some extent although VI also covered activity. Two-thirds of the patients who did not report visual changes turned out to have visual dysfunctions when measured objectively.

In study IV 48 patients with ABI received visual rehabilitation and, compared to a control group with 41 patients, there was a statistically significant improvement in vergence abilities. The control group also showed some improvement, but except for fusion at distance the changes was not statistically significant.

*Conclusion:* More than half of the patients experienced visual changes after ABI, regardless of the type of examination, and some of the patients are not aware of their problems. This strongly indicates a need for visual screening as a part of a neurorehabilitation assessment. VT improved the vision function trained, but more research is needed to examine the effect on activity and participation level.

## LIST OF SCIENTIFIC PAPERS

- I. Berthold-Lindstedt M, Ygge J, Borg K (2017): Visual dysfunction is underestimated in patients with acquired brain injury, J Rehabil Med 2017, doi: 10.2340/16501977-2218
- II. Berthold-Lindstedt M, Johansson J, Ygge J, Borg K (2019): Visual-related symptoms after acquired brain injury and the association with mental fatigue, anxiety and depression, J Rehabil Med 2019, doi: 10.2340/16501977-2570
- III. Berthold-Lindstedt M, Johansson J, Ygge J, Borg K (2020): How to assess visual function after acquired brain injury – Asking is not enough! Brain Behav 2020 Nov 23; e01958, doi: 10.1002/brb3.1958
- IV. Johansson J, Berthold-Lindstedt M, Ygge J, Borg K: Vision rehabilitation as part of neurorehabilitation after acquired brain injury – a clinical study in an out-patient setting. Brain inj. 2020 Dec 9;1-8, doi:10.1080/02699052.2020.1858495



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## LIST OF ABBREVIATIONS

ABI	Acquired Brain Injury
ACRM	American Congress of Rehabilitation Medicine
BI	Base In
BIV-IQ-15	Brain Injury related Vision Impairment questionnaire
BIVSS	Brain Injury Vision Symptom Survey
BO	Base Out
CI	Convergence Insufficiency
CISS	Convergence Insufficiency Symptom Survey
Cpm	cycles per minute
CVQS	Cerebral Vision Screening Questionnaire
D	Diopter
DAI	Diffuse Axonal Injury
DSI	Dual sensory impairment
EMDR	Eye Movement Desensitization and Reprocessing
GOSE	Glasgow Outcome Scale Extended
HADS	Hospital Depression and Anxiety Scale
HADS-A	Hospital Depression and Anxiety Scale- Anxiety section
HADS-D	Hospital Depression and Anxiety Scale- Depression section
ICF	Classification of Functioning, Disability and Health
MFS	Mental Fatigue Scale
mTBI	Mild Traumatic Brain Injury
NFV	Negative (divergent) Fusional Vergence
Pd	Prismdiopter
PFV	Positive (convergent) Fusional Vergence
PTSD	Post-Traumatic Stress Disorder
Q	Question
QoL	Quality-of-life
RCT	Randomized Controlled Trial
RM	Rehabilitation Medicine
SAH	Subarachnoid Hemorrhage

SC	Superior colliculus
SPSS	Statistical Package for the Social Sciences
TBI	Traumatic Brain Injury
VFD	Visual Field Deficit
VI	Vision Interview
VISA	Vision Impairment Screening Assessment,
VT	Vision Therapy

PREVIEW

# **1 INTRODUCTION**

Vision is so taken for granted, it's just there, but at the same time, extremely complicated. Vision guides movements and is fundamental to social behavior and emotions. Vision forms part of our thoughts, memories and dreams. Because of this overwhelming, ongoing input, and its vulnerability to injury, visual function ought to constitute an important factor in brain injury rehabilitation. My hope is that this doctoral dissertation will contribute to such a development.

## **1.1 ACQUIRED BRAIN INJURY**

Acquired brain injury (ABI) affects approximately 40,000 people in Sweden each year and often leads to lifelong disability. Of this total, 25,000 people are affected by stroke (1) and 15,000 by traumatic brain injury (TBI) (2). Four other less common diagnoses are relevant in neurorehabilitation: subarachnoid hemorrhage (SAH), anoxic injuries, encephalitis, and brain tumors.

## **1.2 INJURY MECHANISMS IN ABI**

ABI affects the brain's communication capacity by distorting neural networks. However, the injury mechanism differs in different diagnoses. Stroke is caused by an obstruction or bleeding in a blood vessel. The primary injury gives rise to a secondary reaction, leading to increased cell death and oedema (3). TBI is caused by trauma to the head, such as a fall, assault, or road accident. The injury can be both focal and diffuse. Damage to the white matter, diffuse axonal injury, DAI, is the main reason for chronic impairments after a TBI (4-6). SAH results in the risk of acutely raised pressure in the brain and encephalitis can lead to both necrotic injuries and secondary damage due to immune reactions.

ABI activates the brain's immune system through microglia. These immune reactions are extremely complicated and mostly unknown (7). They can be protective or lead to the destruction of brain tissue. The reaction of the immune system of the brain after injury/illness is a growing area of research and may in the future contribute to the development of new strategies for treating ABI (7, 8).

## **1.3 VISION AND THE BRAIN**

All information about the outside world enters the brain via our sensory systems: vision, hearing, smell, taste and sensation, and in humans, vision is the dominant sensory system (9, 10). Visual impressions arise from reflected light from the environment which is imaged optically in the eye. Processing visual information involves widely spread networks and several areas of the brain (11). Through this process, information about objects, people and their spatial relationships is acquired. The information is used in different ways, to enable the brain to plan movements or other executive functions, form thoughts, or give rise to emotions. It is an ongoing feed-forward and feedback system, and is also connected to memories and other cognitive processes for more complex planned actions (12).

In the next part of this chapter the intention is to provide an overview of the anatomy and the sensory and motor features of visual function.

#### **1.4 THE SENSORY-MOTOR COOPERATION FOR VISUAL PROCESSING**

The cooperation between visual input and the oculomotor system enables processing of visual impressions. These systems function and cooperate continuously to make it possible to direct the gaze to objects of importance, interpret visual impressions and connect them to higher cognitive, emotional and executive functions.

#### **1.5 IMPORTANT CONCEPTS OF SENSORY INPUT IN VISION**

- *Visual acuity* denotes the eye's ability to form a sharp picture on the fovea, i.e. the central part of the retina, and the ability of the eye to resolve details. Changes in the transparent media of the eye, its refractive properties, can be remedied by spectacles (13).
- *Visual field*: The visual field of humans is 170 degrees. The overlapping part, as seen by both eyes, is about 120 degrees (14). All information from the left vision field goes to the right side of the brain and vice versa. Lesions in the retina or along the visual pathways may cause loss of sensitivity in the visual field.
- *Contrast sensitivity*: Contrast sensitivity refers to the ability to discriminate differences in brightness (13). In dimmer light, people or objects may become difficult to detect. When assessing visual acuity, high contrast vision charts are often used so that low contrast sensitivity may go undetected (12). Refractive errors, eye diseases or lesions along the visual pathways may cause reduced contrast sensitivity.
- *Stereopsis*: The ability to analyze the three-dimensional world is of fundamental importance in all visual activities. Since the eyes are separated laterally, each eye provides a slightly different view of an observed object. This difference gives rise to depth perception, or stereopsis. (13). Issues concerning visual acuity, major visual field deficits or oculomotor functions may cause problems with depth perception, asthenopic symptoms or double vision.

#### **1.6 IMPORTANT CONCEPTS OF OCULOMOTOR FUNCTION**

The oculomotor system has three purposes

- stabilizing the gaze
- control of gaze eye movements
- obtaining vergence eye movements

Oculomotor activities depend on complex and cooperating networks present in large parts of the cerebral cortex, the basal ganglia, the cerebellum, and the brain stem. The superior colliculus, SC, is an important hub in these interactions (12).

### **1.6.1 Stabilization of the gaze**

Visual fixation is essential for the ability to keep the gaze steady, so that the image of an object is held firmly on the central part of the retina, the fovea. Failure to maintain visual fixation will cause a decline in visual acuity, for example nystagmus may cause a marked decline in visual acuity and a sense of movement in the visual percept, oscillopsia.

The stabilization of the gaze during brief head movements is secured by the vestibulo-ocular-reflex (VOR). VOR is a combination of networks connecting cerebellum, nuclei in the brain stem and the balance organs (12). Issues concerning the VOR function may cause blurred vision or a sense of movement in the visual percept, self-motion.

### **1.6.2 Control of gaze eye movements**

When the eyes move in the same direction, i.e., conjugate movements, the purpose is to maintain the image of a moving object on the fovea, that is, to track a moving object with the eyes. The eye movements providing this consist of pursuit movements, for following objects, and saccades for fast redirection. The purpose of pursuit movements is to maintain the image of a moving object on the fovea, that is, to track a moving object with the eyes. Pursuit movements also maintain the image on the fovea during self-motion.

Saccades bring the image of an object to the fovea, e.g., when an object of interest appears in the visual field the eyes are redirected with a saccade to point at the object. There are different subtypes of saccadic movements: reflexive, voluntary, anti, memory guided and self-paced saccades (15). Reflexive saccades are a direct response to a stimulus through redirection of the gaze, anti-saccades involve the ability to voluntarily direct the gaze contralaterally from the stimuli and memory saccades direct the gaze to something known to have been there earlier. When reading, small saccades enable progression through a text and change of line. In a medical examination one often just assesses the self-paced saccades.

### **1.6.3 Vergence**

Vergence eye movements, i.e., disconjugate movements, is when the eyes move in opposite directions. The purpose is to hold the image on the fovea in both eyes simultaneously when viewing objects at different distances. Vergence eye movements comprise convergence, vergence facility and fusion vergence, and are essential for maintaining binocular vision close up or far away. Issues concerning vergence may cause asthenopic symptoms, blurred or double vision, and difficulties in shifting a sharp focus in different directions.(13). If the gaze falls out of focus, fusion vergence redirects the gaze centrally.

## **1.7 VISUAL PATHWAYS**

### **1.7.1 The Retina**

Visual processing starts in the retina. Light passes through the different media of the eye and reaches the retina where two types of photoreceptors are present, rods and cones. Rods are sensitive to weaker light (16) and more frequent in the periphery (16). Cones are sensitive to bright light and colors, with highest density in the fovea, and this concentration