Zij weten niet, en verstaan niet, want het heeft hun ogen bestreken, dat zij niet zien, en hun harten, dat zij niet verstaan.

(Jes. 44:18)
When we open our eyes, we see. When we move our eyes over this page we see letters, words and sentences which we can read and understand. When we look up, a panorama of objects unfolds before us. We are able to visually explore the space surrounding us, identify the faces of people we encounter, and are aware of their facial emotional expressions. Our brain makes sense of the light that enters our eyes. Complex brain mechanisms underlie an ongoing process of seemingly effortless visual perception. This thesis focuses on some of the interactions between these brain mechanisms, specific visual impairments after brain damage and the possibilities for rehabilitation, and the distinction between conscious, overt, visual processing and unconscious, covert, perception.

The present thesis is organized in three sections. Section 1 (chapter 2) provides a general overview of the cortical and subcortical brain structures that are involved in visual processing and the way these systems interact. Three visual streams are described: a ventral, occipitotemporal stream for processing information related to specialized recognition of objects and faces; a dorsal, occipitoparietal stream for processing information related to movement, location and motor action; and a subcortical, cortico-amygdalar and thalamo-amygdalar pathway for processing of emotion-related information. Also, some of the most important visual impairments due to brain damage will be discussed.

In section 2 (chapters 3 and 4) rehabilitation methods of damage to specific parts of the visual system will be reviewed.

Section 3 (chapters 5, 6 and 7) consists of experimental studies that focus on interactions between overt and covert recognition of faces and emotional facial expressions. Finally, chapter 8 provides a summary of main findings of this thesis, which will be discussed in chapter 9.

When damage occurs to a brain structure that is directly or indirectly involved in visual processing, visual perception may become impaired. Visual impairments may affect numerous aspects of functioning in daily life, such as reading, mobility, and recognition of other people. Rehabilitation aims at overcoming the consequences of these impairments, either via restoration or compensation. Both restoration and compensation may operate on a neural, cognitive or behavioural level (Code, 2001).
By far, the most frequently occurring visual disorder after acquired brain injury is a homonymous visual field defect (HVFD). In some patients, the field restores to normal size in the first few months post-injury, while some other patients may adopt a form of scanning strategy, which allows them to compensate for their loss of visual field (Pambakian et al., 2004). However, in most patients spontaneous compensation is absent or insufficient, with severe consequences for activities of daily living (ADL) (Zihl, 1995). Typical complaints of patients with HVFDs are difficulties with reading, and poor detection of people or objects in the contralesional side, leading them to bump into obstacles or people.

In *chapter 3* (Bouwmeester et al., 2007), a systematic review assessing the effects of systematic visual training for patients with HVFDs is presented. Current training methods for HVFDs can be divided into two categories. The first category, vision restoration therapy (VRT), consists of methods aiming at restoration or restitution of a part of the HVFD. VRT aims at increasing the functional visual field by reactivating surviving neurons in the (partially) damaged brain through repeated presentation of light stimuli in the border area of the HVFD. The second category of rehabilitation methods, scanning compensatory therapy (SCT), aims to enlarge the field of search by training patients to make eye movements into their blind hemifield. The objective of the systematic review is to evaluate whether VRT and SCT lead to (1) restoration or restitution of the visual field (i.e. lead to a reduction in the size of the HVFD), (2) an improvement of scanning strategies (i.e. lead to an increase of the size of the visual search field, and (3) an improvement in ADL.

One of the most common and dramatic impairments after damage to the dorsal stream is unilateral spatial neglect. Like patients with HVFDs, neglect patients show poor reading and may ignore objects or people that are located on their contralesional side. The crucial difference with HVFDs though, is that in neglect these symptoms are not caused by a deficient cortical representation of the visual field, but by a deficient representation of attentional and spatial cognition (Robertson & Heutink, 2002).

In *chapter 4* (Robertson & Heutink, 2002) an overview is provided of rehabilitation methods that have been developed during the past decades. Several methods have been clinically evaluated, while other, more recent methods are still experimental. Some of these recent methods nevertheless are of particular interest.
since they demonstrate the potential value of interactions between the visual processing streams.

Brain injury affecting the ventral stream for visual processing can result in impaired perception and recognition of faces. Numerous studies have shown that in prosopagnosia, the complete inability to recognize previously familiar faces, covert face recognition may be still preserved (Barton et al., 2001; Barton et al., 2004; Bauer, 1984; De Haan et al., 1987; De Haan et al., 1992; Young et al., 1988). Covert face recognition may reflect processing via dorsal or subcortical brain regions (Bauer, 1984; Gobbini & Haxby, 2007), although other explanations have been put forward as well (De Haan et al., 1992; Farah et al., 1993). In Capgras delusion, which refers to the belief that close acquaintances, such as parents or children, have been replaced by impostors, robots or aliens, overt recognition of faces is intact, while covert recognition is impaired (Ellis et al., 1997; Ellis et al., 2000; Hirstein & Ramachandran, 1997).

In chapter 5, a rare case is presented of a woman who displays some characteristics of prosopagnosia and some characteristics of Capgras delusion. In this study, response accuracy, response times and skin conductance response (SCR) to different categories of familiar and unfamiliar faces are assessed to establish whether mechanisms for covert and overt face recognition are intact or impaired.

The past ten years have seen a growing interest in the topic of visual processing of emotional information. In particular, subcortical and cortical processing of facial emotional expressions has been studied. LeDoux’ influential model argues that there are two semi-independent pathways for processing emotions (LeDoux, 1996). In this model, the ‘low road’ receives coarse input directly from the thalamus, allowing fast responses to emotionally significant stimuli. Via the ‘high road’, the amygdala receives elaborate input from cortical structures. Several neuroimaging studies have shown that activity in the extrastriate cortex is functionally correlated with amygdala activation in response to emotional facial expressions and fear-conditioned faces (Morris et al., 1998; Morris et al., 1999), suggesting an interaction between cortical and subcortical streams that are involved in emotional processing.
In chapter 6, a study employing event-related potentials (ERPs) is presented, that investigates early, pre-attentive processing of facial emotional expressions and fear-conditioned faces.

In chapter 7, a male patient with a right-amygdala lesion is presented. This patient has impaired overt recognition of facial emotional expressions. In particular, he is unable to tell the difference between an anxious facial expression and a surprised facial expression. Employing ERPs, processing of emotional facial expressions and fear-conditioned faces is assessed. The results are interpreted in terms of covert and overt processing of emotion-related visual input via cortical and subcortical brain structures.

Finally, in chapter 8, the results of the different studies in this thesis are summarized, while in chapter 9 these results are compared and discussed in the light of interactions between the visual processing streams, distinctions between overt and covert visual processing and prospects for rehabilitation.
References


Section 1

Introduction