Visual perceptual skill learning after long-term blindness

The reason of the laborious work

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Abstract

Visual perception is a process starting with the arrival of light information in our eyes and retina, followed by several steps in various brain areas along the pathway of visual information processing. During this process sensation becomes perception. Perception, however, only exists if the observer has a meaningful representation, which is built up from the moment we have visual experiences.

Unlike normal visual development in infants, the process of learning visual perceptual skills turned out to be surprisingly laborious and frustrating when long-term blindness patients gained the possibility to perceive visual information after an operation. These patients were diagnosed with congenitally impaired ophthalmologic conditions and were operated at a much later stage in their life. Similar visual deprivation conditions were known using animal experiments in which animals were raised under visual deprivation conditions. The conclusion from the animal experiments was that lack of proper visual experience during the 'critical period' diminishes visual cortical development and subsequent learning process permanently. This critical period was considered the very reason that later visual learning efforts were seen as a fruitless enterprise.

Despite the major skepticism towards later learning, visual rehabilitation in some case studies showed improvements. This reflects the possibility of visual learning at a later stage in life, and therefore other factors initiating the learning process seem to exist. Recent studies support this view. In this thesis, existing patient reports are analyzed and the potential influential factors will be discussed.

Contents

Chapters

1. Introduction

1.1 Visual perception development studies in animals and critical periods

1.2 Long-term blindness patient reports

2. Background information

2.1 Visual perception

2.1.1 Definition of visual perception

2.1.2 Levels of visual perception

- Unconscious vision and blind sight
- Conscious vision

Reality and Illusion
Ambiguous figures
Visual completion

2.2 Discussion

3. Current long-term blindness patient studies and remained questions

3.1 Project 'The Prakash' and rehabilitation program

3.2 Outstanding questions about visual perceptual development

4. Case reports analysis

4.1 Background

4.1.1 Residual visual skills and initial status of the patients

4.1.2 Visual skill development in infants

4.2 Subconscious visual skills in long-term blindness patients

4.3 Conscious visual skills in long-term blindness patients

4.4 Cross modal visual skills in long-term blindness patients

5. Potential reasons for the laborious learning

5.1 Ophthalmologic conditions of pre and post operation

5.2 Neural plasticity

5.3 Education and other sensory modality dependency

5.4 Psychological condition

6. Conclusions and suggestions

7. References

1. Introduction

Is perception only visual? The fact that our senses often need to interact with each other to come up with an interpretation of the world, the answer is likely to be 'no'. Then, how do the eyes and other senses supply our brain with the information about objects in the world? Once reflected light from an object reaches the retina, several neural processes start in the visual pathways and end with the perception and recognition of an object. That is, the light information is converted and connected to our knowledge, and as such, the information becomes meaningful.

1.1 Visual perception development studies in animals and critical periods

The importance of visual experience in visual perceptual skill development was demonstrated by the studies of visual cortex in animals. It was proven, especially through visually deprived kittens and primates, that the development of visual cortex is highly dependent on early visual experience. Wiesel and Hubel (1963) conducted kitten visual cortex experiments under diverse visual experience deprivation conditions. Their paper reported on the effect of a surgically closed eyelid in visually inexperienced kittens. That is, before the time the eye normally opens after birth. So the cat only had monocular visual experience until the age of 3 months. Electrophysiology revealed that the visual cortical neurons of the deprived side were significantly less active in comparison to normal adult cat visual cortical neurons. Histology showed that the neurons connected to deprived eye were shrunken remarkably (Wiesel and Hubel 1963a). Another study in the same year showed that the response of the neurons in the striate cortex was diminished. Also receptive-field organization in the visual cortex was poor compared to a normal matured visual cortex (Hubel and Wiesel 1963b).

When kittens were forced to use the previously deprived eye, it showed the kittens were behaviourally blind. However, I an adult cat with the same deprivation condition there was no observed consequence of the condition. Hubel and Wiesel concluded that lack of proper visual experience in the early developmental phase is permanently detrimental to the visual cortical circuit network and stops visual perceptual development. This observation was linked to the concept 'critical period' which Konrad Lorenz derived from the result of imprinting in young birds (Lorenz, 1937).

1.2 *Long-term blindness patient reports*

It is ethically impossible to use the same experimental paradigms in human beings. Nevertheless, there are a few studies about the same topic in humans. These studies were done with rare cases of blind people who suffered from prolonged congenital blindness until their adulthood. The problems arouse at a very early age (4 months). The ophthalmic conditions were hindering normal light passage from the cornea to the retina by congenital malformation of the eye structure such as, cataract, aphkia or severe corneal keratitis. Although treatable at the time, operations were too expensive. The problems with light transmission frustrated visual skill development during the important early phases. If the visual skills do not properly develop during the sensitive periods, future visual perceptual learning becomes hard.

After an operation, some of the problems were solved - or at least some of the obstructions were removed - and the patients could potentially see. Therefore, they were tested for their visual perceptual performance after some visual skill training. Surprisingly, they had some residual visual skills. They also showed some improvement in visual skill learning despite the short period of rehabilitation program training. Another interesting observation is that some of them could associate their limited visual skills with experiences from other sensory modalities like touch (tactile sensation). The most remarkable example is SB, a case report by the late Richard Gregory (Gregory & Wallace, 1963). This observation had severe implications as it changed the widely held concept of critical periods. It seemed to show that humans *could* learn visual skills after regaining of their sights at a later stage in their lives. Nevertheless, the developmental process was not like the natural visual skill developmental process in infants. It was processed even slower and gave extreme distress to the long-term blindness people. Some of them even gave up further visual skill training.

What would be the reasons for this difficulties in visual learning? Why is there such a huge difference in visual learning for infants and these older patients? The answer to this question could be suggested by comparing the cases of the patients to normal infants. By comparing cases and analyzing them in terms of ophthalmologic and neuropsychological aspects, the answer can be drawn. Knowing the difference between two developmental processes and the reason behind of it could work as the basis for building better rehabilitation program for these rare long-term blindness patients. Based on the analysis result, potential reasons of observed difficulty in visual skill learning in the patients will be introduced. Finally, provisional rehabilitation way to help the patients will be suggested.

2. Background Information

2.1 Visual perception

2.1.1 Definition of visual perception

One of the most known definitions is 'The process of acquiring knowledge about environmental objects and events by extracting information from the light they emit or reflect' (Palmer, 1999). Also, visual perception is often regarded as visual awareness or a visual experience. Studying consciousness is highly dependent on reports of the observers. The common denominator is that visual perception is an active construction of our brain, rather than an automated process.

This idea can be described by comparing it to a device of the initially resembles our visual system, a camera. The film in a camera can be compared the retina and a camera lens to the optical lens in the eye. Like the lens aperture, the pupil size is regulates the amount of light reaching the retina. Beyond the retina the analogy does not hold as it becomes a constructive process. That is, cameras record the image of a scene and do not process it further. Our brain does and our representations in the brain contain knowledge of the image that can be developed in almost every possible way. The information can be connected to many representations that are stored in our memory and a such new representations can be composed and eventually represented or stored in memory. This processing is considered to happen at the cognitive levels in our brain.

2.1.2 Levels of visual perception

As our conscious is currently known to be in several levels, the process that leads to visual perception also happens in multiple levels. The levels can be roughly split into two; one for conscious perception and another for subconscious visual perception. Although we have vivid experiences, we are using our subconscious visual skills without being aware of it. Perhaps the role of these primitive subconscious visual skills is to survive and it is essential in terms of evolution. Either way, both visual skills are the results of the orchestrated work of the eyes and associated brain area. However, there are major differences between the pathways as shown for example by studying lesions in the visual system.

Unconscious vision and blind sight

One of the most famous cases of subconscious visual skills can be observed in so called *blind sight* patients. These patients typically have brain lesions in primary or striate visual cortex (also known as area V1). This area is essential for conscious vision (Tong, 2003). Blind sight refers the residual sight covering the external world in this damaged area. Their performance of visually-guided behavior and movement/direction detection tasks are above chance level, even though they claim not to be aware of the target objects (Weiskrantz et al., 1974). So, although the patients are not consciously aware of the object, they show visually-guided behavior and can detect moving stimuli, probably through the subconscious visual pathway. These pathways are generally known as the retino-tectal pathway and the geniculo-extrastriate pathway (See Figure 2.1).

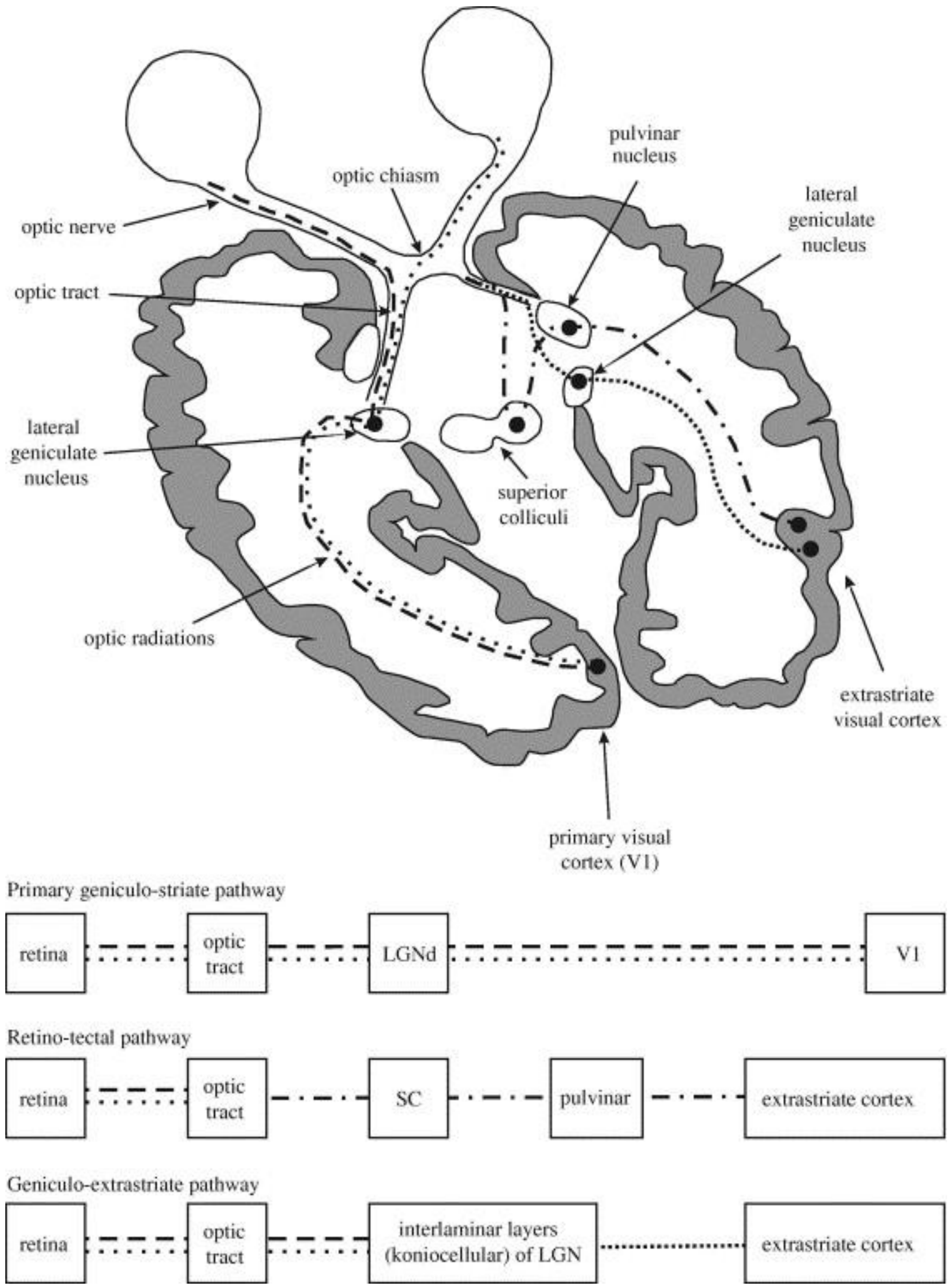

Figure 2.1 Visual information pathways bypassing primary visual cortex (V1): The retino-tectal pathway, and the geniculo-extrastriate pathway (Figure adapted from Danckert, 2005)

Conscious vision: non-veridical perception

A well-known Belgian surrealist artist René François Ghislain Magritte is famous for a number of ambiguous paintings. In one of his paintings he put a famous phrase "Ceci n'est pas une pipe" ("This is not a pipe"). He meant to say that the image of a pipe is an image of it but not the real object. It is a representation! Using these kind of paintings, he wanted to point out our tendency to perceive images in biased ways. Following his idea, observers are likely to perceive in a subjective way rather than a veridical way. There are several examples showing that the difference between perceived and physical representations of objects, some of which are displayed in Figure 2.2.

Reality and Illusion

The famous Müller-Lyer illusion shows the principle outlined above. The explanation of this illusion is based on previous visual experience. Richard Gregory described this illusion occurs because our visual system makes the wrong assumptions. Our visual system assumes that if it is the “angles-in” configuration, the object is closer and the object of “angles-out” is distant. This experience-based assumption gives rise to many optical illusions in unusual scenes (see Gregory, 1966 for an overview). The examples show again that our vision is already biased by our previous visual experiences, and as such that we cannot veridically perceive the world.

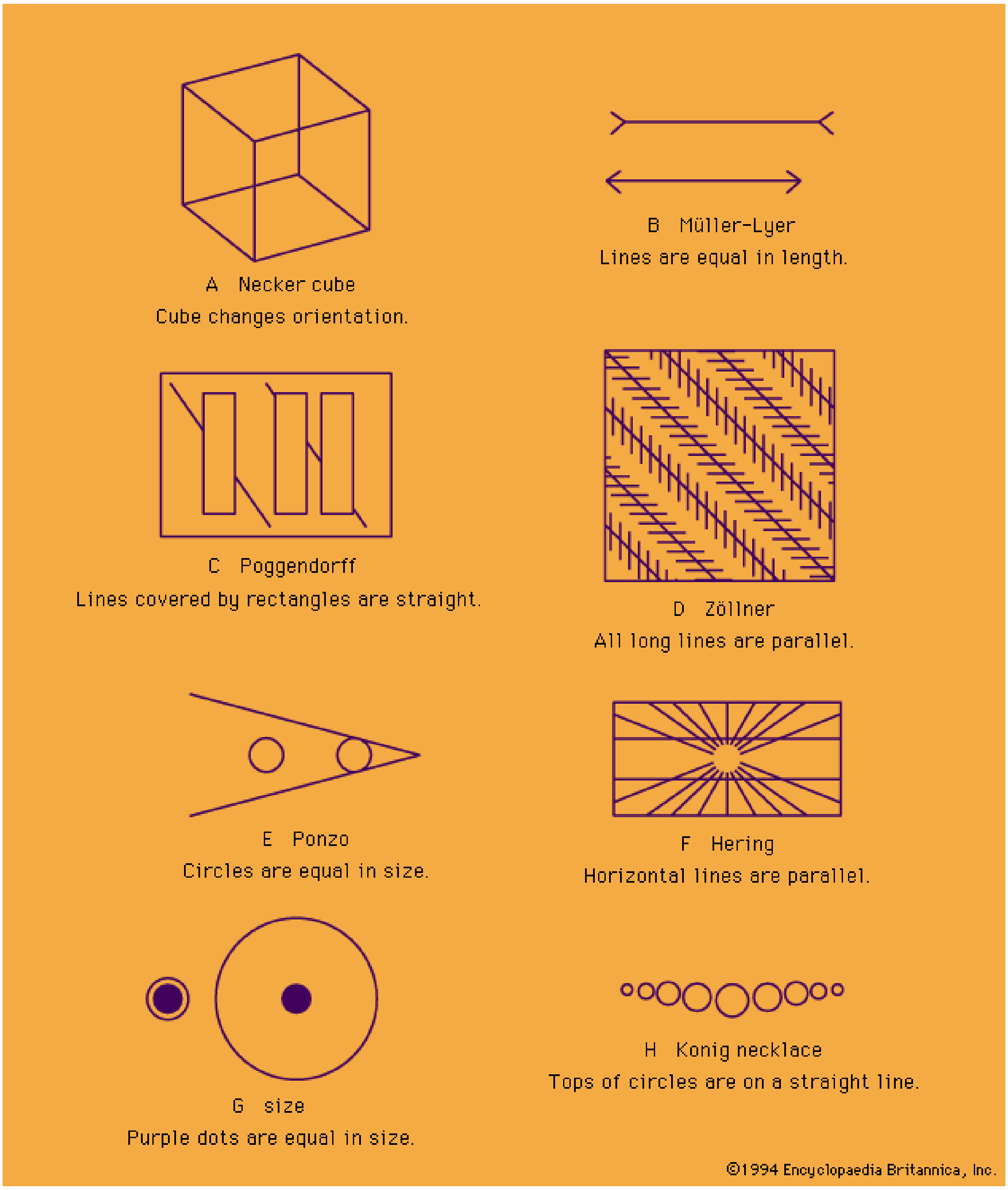

Figure 2.2 Examples of some optical illusions (Figure from Encyclopædia Britannica Online, 17 Sept. 2007)

Ambiguous figures

Another example of the subjectivity of visual perception is the famous ambiguous figure known as the Necker Cube (Figure 2.2) reported by Swiss crystallographer Louis Albert Necker in 1832 (David Marr, 1983). The Necker cube can be interpreted in two ways because of the ambiguous orientation cues of the cube. The perceived interpretation alternates and as such it is not possible to perceive a stable image of the cube for a longer time. This is due to the fact that the three-dimensional cube is presented on a 2D surface. Interestingly, most of the people tend to interpret the image with the lower-left face as being in front. This fact shows another example explaining that perception is based on our visual experiences. Our brain chooses the cue and comes up the most common interpretation (given that we look at objects from above more often than the other way around).

Visual completion

In addition to interpreting illusionary and ambiguous images, our visual system also fills gaps of objects and completes missing parts to come up with an whole object representation. This is especially observed in visual completion tasks. In Kanizsa's figure we tend to perceived the image as square placed on several circles and complete the hidden contours of circles. This is a basic component of visual perception for form and object recognition. The mechanisms underlying subjective contours is believed to be located in areas V1 (Lee & Nyugen, 200x) and V2 (see Von Der Heydt & Peterhans, 19xx). In a study of subjective contour perception, the interaction between visual areas V1 and V2 was proven to be important (Lee, 2001). It was shown that area V2 responds to illusionary Kanizsa's figures earlier than area V1. The response in V1 was following the response characteristics of those in area V2. They concluded that visual contour completion is based on an interconnected network between the two areas serving global contour detection (V2) and spatial detail (V1).

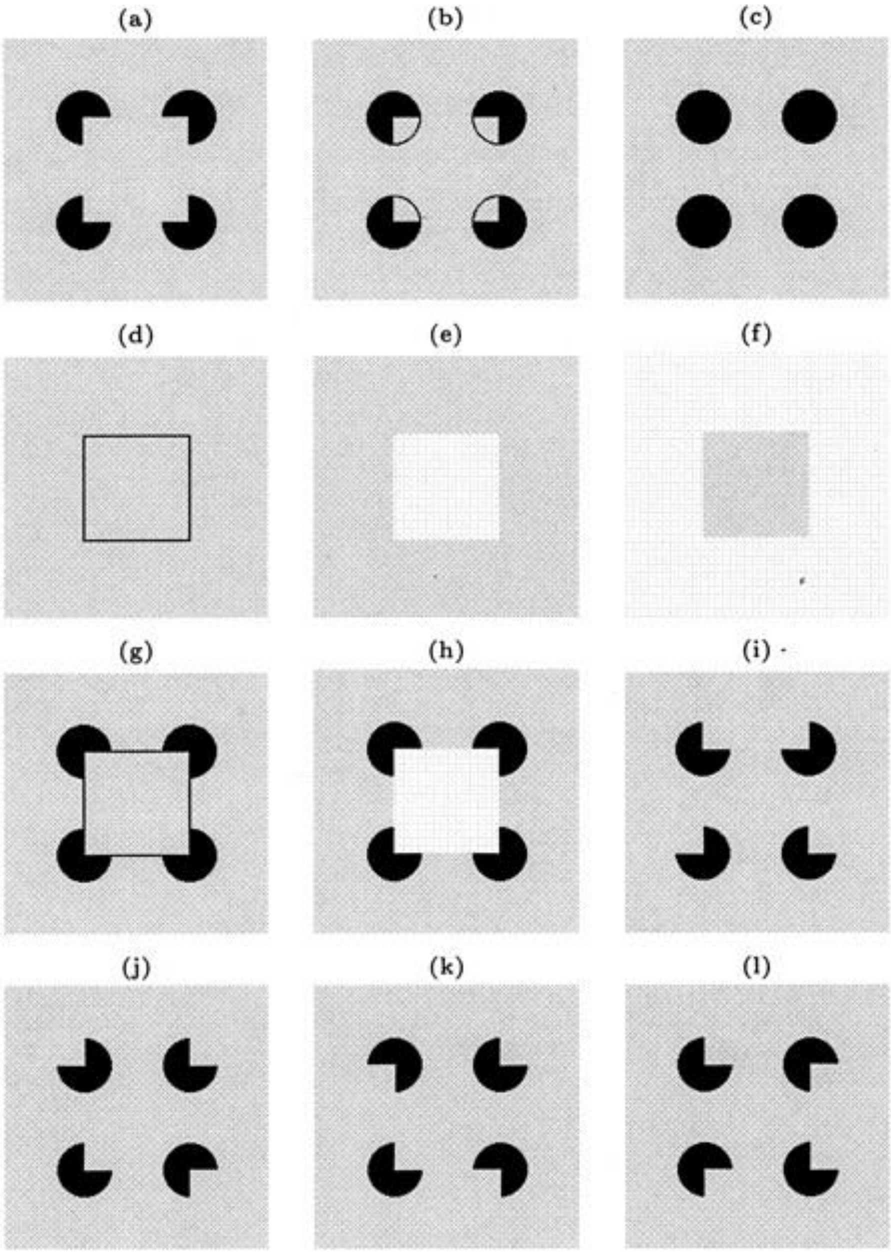

Figure 2.3 Kanizsa's figures (Figure from Lee, 2001)

2.2 Discussion

As previously discussed, our visual percept is composed of distinctive levels, operating on a conscious and unconscious level. Some visual skills are unconscious and possibly represents a mechanism essential for survival. The other category works for higher level of visual perception. Depending on the visual requirements there are distinct neural substrates involved. The role of the primary visual cortex (V1) is important to produce conscious visual experience and other areas in the extrastriate cortex are involved depending on the visual task at hand. Most important, however, is that fact that these areas are interconnected and are – as a network – responsible for our current percept, where our past visual experience plays a crucial role.

3. Current studies of visual perception development and outstanding questions

3.1 Project 'The Prakash' and rehabilitation program

After about 40 years after Gregory's study of subject SB (Gregory & Wallace, 1963), the most recent case studies come from the group of MIT based Pawan Sinha (Mandvilli, 2006; Sinha, 2003)'. This project, named 'Prakash' is based on the humanitarian work for the children born with congenital cataract in India.

One subject. SRD, was born blind, and remained so until she was 12 years old. The study started 20 years after the operation and they found that though her visual acuity was still poor, she had mid to high level of visual proficiency. The researchers concluded that her visual task proficiency is developed by learning and self-training during these20 years. This indicates that the human brain was still able of visual learning at least until later childhood. The research group showed that the concept of *critical period* is not necessarily applicable to human beings. This conclusion gives new possibility for treating long-term blindness people in their later lives.

3.2 Outstanding questions about visual perceptual development

So, several reports disapproved the traditional view on developmental stages . The observations by Gregor and later by Sinha clearly showed the possibility of visual learning during later life. However, there were still remaining questions. One concerns the issue why the learning process in long-term deprived vision is hard and so distressful.

To set up proper rehabilitation program, it is important to understand the difference between the two groups we have discussed so far: infants and long-term blindness patients. By comparing them, we might understand the differences in the underlying mechanisms which could lead to a justifiable rehabilitation program.

4. Case reports analysis

4.1 Background

4.1.1 Residual visual skills and initial status of the patients

Most known cases have congenital cataract as the origin of their ophthalmic condition. The opacity of the lens disrupts the way in which light reaches the retina. These patients were treated by an operation in which the bad lens was removed and. Another lens was implanted or glasses were supplied. Another case was born with the condition known as congenital bilateral aphakia. His eyes developed without a lens and he was given glasses to compensate for that.

The second most frequent ophthalmic condition are complications associated with corneal damage. Patients like SB, HD and MM[1]. had severe corneal damage: corneal graft (SB, HD) and corneal limbal cell transplant (MM). Before the treatment they mostly had light perception and some of them had even certain degree of acuity However, their visual acuity was still severely limited. The reason is likely the visual deprivation in childhoods

4.1.2 Visual skill development in infants

Activation of the visual system already starts before eye opening through stimulation on closed eyelid (K Krug, 2001). Visual acuity and contrast sensitivity of newborn infants are known to be assessable but very rudimentary. In normal infants, the skills of focusing, gazing, smooth pursuit eye movements, and eye-hand coordination develop within the first 6 months. At 4 weeks, grating acuity and contrast sensitivity are measurable by behavioral measures (preferential looking) but are very limited. The temporal resolution is ~40 Hz which is quite similar to adults. Basic color vision can be shown by 8 weeks. Red, blue and green is the most distinguishable at that age. Along with color vision visual acuity develops continuously. Motion direction coding also happens at this time and is completed by 3 months. By the time of the first 4 to 6 months, the infant's brain has binocular integration, resulting in good depth perception. As a result, recognition of a spatial dimensional concept continues to improve as infant learns to aim accurately when reaching for objects of interest. Binocular rivalry was also observed in infants of this stage.
The higher visual skills such as, object segmentation and recognition and figure-ground differentiation are seemingly not happening in infants before 6 months.

[1] SB:Gregory & Wallace, 1963;
HD: Ackroyd, 1974;
MM: Fine, 2003.

4.2 Subconscious visual skills in long-term blindness patients

'Unconscious vision' tasks were conducted to measure to what degree the patients show visual behavior despite the fact that they are technically blind. The tasks, although very diverse, were all aiming at testing navigation, motion detection skills and visually guided movements.

H.D. (Ackroyd, 1974) conducted qualitative and quantitative tasks and showed dramatic responses. For the qualitative observation she performed a spatial vision task, in which she – while walking – had to avoid large obstacles such as trees and walls which she insisted to have seen. The tasks for movement vision, seeing/detecting moving objects were the easiest for her. Her most vivid visual impression was described when viewing through a window of a moving car. She could also follow the movement of bright moving object with her finger. Quantitatively, for the movement detection task, moving stimuli were provided with speed of 10cm/s and she almost never failed to detect whether the stimulus was moving or stationary. The same was true for the direction of movement. In object presence detection task, she was good at detecting the presence of the object. In another task, she could indicate the randomized location of a block with reaching arm/hand movements. This task is now known as "the test of visually-guided hand movement".

Calson (1986) studied a Zambiaze patient , which I will refer to as Z initially could direct his gaze towards an object and follow the object's movement. Z could pick up visually-guided small objects, with some delay in performance time. In all other visually guided hand movement tasks such as, the labyrinth test, drawing a line between two spots, Z performed above chance at the beginning and showed improvement during the training.

Fine (2003) had MM perform more diverse visual tasks concerning motion detection. In line with other case reports, MM's visual skills to detect motion was successful for many tasks. Addition to the usual motion detection tasks, illusionary images with motion cues were shown. Stationary 3D or illusionary images could not be apprehended by long term blindness patients like MM. However, the barber poll illusion and 3D Necker cube images with motion cues were possibly understood by MM. This is supporting view that long term blindness patients detect motion. In the report of MM it was suggested the middle temporal area (MT) was responsible for this ability to perform motion tasks. The researchers observed normal fMRI signals in the area MT. From a recent study of global motion detection in blindsight patient, the role of area MT in this context was supported. Also, transcranial magnetic stimulation (TMS) over the area MT showed diminished motion detection performance in blindsight patients (Alexander, 2009). This suggests that motion detection in long-term blindness patients is like that in blindsight patients. The preserved motion detection skills in long-term blindness patients might be due to a preserved function of the extrastriate cortex as previously discussed.

4.3 Conscious visual skills in long-term blindness patients

For all reported patients, the fields of view appeared to be very narrow, and their depth perception to be poor. They could recognize some objects but when confronted with human faces, recognition failed. The same holds for gender or mood through facial expressions. These observations are highly related to immature binocular vision and lack of visual experience. This further indicated the role of higher visual skills. Also, they could not understand ambiguous depth illusions such as the Necker cube or Ponzo illusions (Figure 2.2) and no binocular rivalry was observed. In the case of subject SB, ambiguous and illusionary images like the Hering illusion and the Zolner illusion (Figure 2.2) did not result in any perceptual error. SB could correctly detect the size of images which normally produce perceptual errors in most people.

The lack of higher degree of binocular vision for interpreting illusionary images could be directly connected to the deprivation of binocular experience. For conscious visual skill development, receiving normal visual input with some degree of acuity is crucial. The highest visual acuity at the retinal level is represented by the foveal area. The acuity at this area continues to mature through the first four years of age (Hendrickson & Yuodelis 1984). Foveal immaturity brings losses to other visual skills development such as binocular vision and depth perception and stereopsis (Teller, 1997). Any failure in acuity and contrast sensitivity will affect the development of many other visual skills. Binocular vision develops from the first several months However, depth perception improves until the age of 9 years. The early onset of cataract hindered the acquisition of mature binocular vision. Although these patients gained a moderate degree of visual acuity through operational correction, the lack of development of binocular visual skills made the patients frustrated about the operation results.

4.4 Cross modal visual skills in long-term blindness patients

Another visual skill in consciousness vision concerns form and object recognition. This skill is known to be highly based on previous knowledge and experience. The truth that some patients could use their early tactile experience to object recognition is a very interesting observation. For example, in the case report of SB, his reading skill were puzzling. In a word, he could only recognize lowercase letters which he had previously learned in Braille. Furthermore, he could draw a car and house but all were incomplete. The missing parts of the drawings were based on his limited tactile experience, in which the parts he could not touch were missing in the drawings. His previous knowledge helped him to have a brief idea about how to differentiate colors. Important to note is that he obviously used his previous knowledge and experience. These representations were built on information he received from other sensory modalities, in this particular case 'touch'. This cross-modal transfer was possible even when the tactile experience/representation was acquired long time ago.

It is commonly observed that in blind people, the function of other perceptual modalities is enhanced. This has been shown in the occipital cortex which is activated by non-visual stimuli. The fMRI experiments with early blind people induced by retinal impairment showed that auditory (Gougoux et al., 2005) and tactile (Stilla et al., 2008) stimuli processing activated several occipital areas. General occipital area activation through multisensory modalities was observed in the study of Renier and colleagues (2010). In their study, activity in the right middle occipital gyrus (MOG) activated showed specific roles for spatial and non-spatial processing in both auditory and tactile stimulation conditions. This activation was also associated the behavioral performance (sound localization). These observations show that the striate cortex or occipital regions can integrate information and act as a multisensory modality, covering vision and other modalities. Moreover, that extrastriate cortex is still working for specialized information processing to complete sensory experiences. This could potentially explain the cross modal transfer shown in long- term blindness recovery patients.

5. Potential reasons for the laborious learning

It is now obvious that the lack of proper visual experience frustrates the development of higher visual faculties. This was shown as veridical perception and unusual interpretation of illusionary images. For example, adding motion in the images helped to interpret the images for patients like people with normal vision do. This reflects the preserved function of the extrastriate cortical areas, like the area MT to detect motion. Rehabilitation showed improvement of visual skills in the patients. Yet, it was slow and painful and most of them were ended up or even preferred going back life as a blind person. Of course, the training periods were too different to compare them with normal development in infants. So it is hard to make firm conclusions at this point.

Donald Hebb (19xx), however, stated that sight is a skill acquired gradually and painfully, even in normal infants. This conclusion was based on his study with former cases of long-term blindness which were reviewed by von Senden (1960). He also proposed that the visual perception development in infants is the same as for people who recovered sight after long-standing blindness. However, this idea was not accepted as there was no reasonable explanation. Stronger, he disregarded the difference between normal infant eyes and poorly operated cataracts and other important factors. Several reasons for the delayed and laborious visual skill development in long-term blindness patients can be suggested:

5.1 Ophthalmologic conditions of pre and post operation

Normal visual skill development in infants for example in the lateral geniculate nucleus and striate cortex activation starts even when the eyelids are closed. This shows that our visual system experiences visual stimuli much earlier than initially believed. This is likely to have happened in long-term blindness patients. However, the pattern of visual skill acquisition with cataract eyes and normal eyes must be different.

The effect of abnormal visual experience on orientation selectivity maturation in ferret visual cortex was observed in an experiment using two different eye condition paradigms (White, 2001). Ferrets were raised either in a complete dark environment or with binocular eye lid suture. They found that the development pattern in the visual cortex for orientation selectivity in the lid suture condition is much more abnormal than for the dark reared condition. The cortical development pattern in the dark reared condition was similar to normal condition except for a weaker maturation. They concluded that visual experience is required for maturation. However, it could be detrimental and it is dependent on the status of the experience. This result can be translated to patients. They could get visual experience resembling the situation with the lid suture. This could be responsible for the abnormal maturation of the visual cortex.

5.2 Neural plasticity

Learning new skills, like learning a new language, needs flexibility in our brain. This is called neural plasticity. It is generally acknowledged that acquiring a language is more difficult, if not possible, after a certain age in adolescence. Like a language, if we want to develop a skill, it should be trained on a regular basis not just during a special training period. In an experiment with neonatally hemidecorticated kittens, the kittens could use visual information from their contralateral hemicortex but adult cats could not (K Norrsell, 1983). The reported patients were mostly over 20 years when they received treatment for their eye condition. The visual skill learning is clearly not be the same as in infants whose brain - at that stage in their development – is much more plastic.

5.3 Education and other sensory modality dependency

Unfortunately, most reported patients were not able to follow proper education specialized for their condition. It was previously discussed for the case of SB that tactile experience of objects can help achieving visual recognition of the objects. Reading Braille and touching objects lead SB to recognize upper latter case and draw cars. Even though it was limited to the extent of the tactile experience, the limitation also shows that the effect of education and learning through other sensory modalities. Thus, education is essential factor to improve visual skills learning process. On the other hand, we could also see the prominent side effect of using other sensory modalities. The patients could not avoid not using other sensory modalities which were substituting vision. This dependency let them settle in previously used modalities rather than trying their newly given modality.

5.4 Psychological condition

It is hard to change our habits especially those which make us more comfortable and convenient. And as usual with learning, no pain no gain. It was apparent that the cause to end or pause the visual training in patients was often for emotional reasons. Thinking that they would get all the visual skills at once after the operations, they were only disappointed. Consequently they were frustrated by the result of operation even though they were much better equipped to experience vision.

6. Conclusions and suggestions

Despite of the factors, outlined above, which were detrimental to the recovery of visual perceptual skills, there were clear improvements during visual training in the rehabilitation period. In a representative case of Carlson (1983), the patient's performance was measured as a function of time. The improvement at the end of rehabilitation was obvious. Also, the pausing during the rehabilitation showed a significant effect on the performance in subsequent trials. This shows the possibility for recovery through adult brain plasticity and the importance of the use of the visual skills in a daily manner. The neural plasticity of the adult mammalian brain has been demonstrated by monkey models (Pons et al., 1991).

Also, the possibility of functional reorganization was shown in the rehabilitation program for patients with phantom limbs. These patients suffer pain sensations at locations on the amputated limb. As a therapy visual stimuli were used that were mirrored to induce reorganization of neural circuit. It was found that after training, the patients could eliminate the pain by altering the body image representation (Ramachandran, 1996). It was concluded that the reorganization of neural circuits for sensation was made in the brain but that treatment program should be repeated frequently to make the reorganization stable.

The concept of critical period which puts a limit on visual perceptual learning in certain time period is more flexible that previous thought. It is true that there are sensitive time periods for learning skills fast and easy. So if there is a delay in acquiring these skills, it will need more time, effort, and motivation. The nature of visual perceptual skill development is sequential. Once the first step is missed, it is almost impossible go further due to lack of a basis for the next step. Implications of missing step could bring out – and explain - the frustration and lack of motivation for further learning.

It is clear that the rehabilitation for long-term blindness patients should also be considered from a neuropsychological point of view. Also, the residual visual skills should be identified by conducting more detailed visual tasks. Depending on the identified visual skill status, the training program should be designed individually.

Immediate treatment, that is, as early as possible, and consistency during the training are the key factors for faster recovery (Paolucci, 1998). An effective rehabilitation program should focus on the initial visual skill training and continue to mature initial skills, long after the improvements are evident. One has to keep in mind that it takes more time than the usual normal development process. Also, since specific restrictions will surround the patients, the environment, especially the educational context of the patient, should be optimized.

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