Eye-tracking and immersive virtual reality as a means to improve the assessment of visuospatial cognition.

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Abstract

How can eye-tracking and virtual reality be used to improve on assessment and rehabilitation of spatial cognition. This master thesis will attempt to answer that question by investigating what kind of issues there are with the common assessment- and rehabilitation methods used in spatial cognition. It does so by investigation the syndrome spatial neglect, what it is, how it is assessed and rehabilitated and evaluating on the current methods used. The traditional pen-and-paper-tests have issues with ecological validity and sensitivity. The thesis will then evaluate eye-tracking and virtual reality as research and assessment tools and give suggestions as to how eye-tracking and virtual reality can be used to assess and rehabilitate spatial cognition. Conclusively it is possible to use eye-tracking and virtual reality to improve on some methods of assessment and rehabilitation, by creating a safe virtual environment in which different tasks, inspired by the traditional tests can be implemented. By using eye-tracking to record data on where the patients look and what they fixate on it might be possible to create a more sensitive system than the traditional tests.

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1.0 Intro

This masters-thesis will attempt to find a way to use eye-tracking and virtual reality to improve on assessment and rehabilitation of visuospatial neglect. It does so by presenting an introduction to what spatial cognition actually is, how we as humans navigate in the world around us, what environmental scales are and how they can have an effect on how the current pen-and-paper-methods of assessment and rehabilitation of visuospatial neglect handle these and then narrow in on what issues there could be with assessment of spatial cognition. A common way of investigating spatial cognition is by examining and testing patients suffering from spatial inattention, since issues with spatial cognition often is easier to research through the symptoms of a patient with deficits than it is to investigate a completely healthy person. A common type of spatial inattention is spatial neglect, and this thesis will focus primarily on this disorder. In order to fully understand this disorder, the primary cause of spatial cognition, stroke and the mechanisms and processes behind it, will be presented. Once the primary cause of spatial neglect is understood, the syndrome itself will be presented and be investigated more in depth. Once the syndrome has been presented and investigated, the assessment and rehabilitation methods will be presented and evaluated. This is done in order to find the issues that may be with the traditional ways spatial neglect is tested, assessed and rehabilitated. Afterwards another way of testing spatial cognition, the UFOV will be presented and evaluated upon. Next the common eye-tracking methods and equipment will be presented and evaluated in order to gain an insight as to how this method may benefit assessment and rehabilitation of spatial neglect. Afterwards virtual reality as a research tool will be presented and evaluated in order to work out how this method may improve on previous assessment and rehabilitation methods. The positives and negatives of the two research tools will be examined and evaluated, both as singular tools and as a combination. The methods will then be evaluated and discussed as tools for improvement of assessment and rehabilitation of spatial neglect and as an improvement on the UFOV. How the methods can be combined with methods from the traditional pen-and-paper-tests could be an interesting discussion, which could lead to new possibilities for assessment and rehabilitation of spatial cognition. Lastly, it will be concluded on how eye-tracking and virtual reality can be used to improve on the assessment and rehabilitation of spatial cognition.

2.0 Problem definition:

How can eye-tracking in immersive virtual reality, be used to improve the assessment and rehabilitation of visuospatial cognition?

3.0 Visuospatial cognition

What is visuospatial cognition? In order to work out how eye-tracking and immersive virtual reality can be used to improve on the current methods of assessment and rehabilitation visuospatial cognition, it is necessary to understand the mechanics of it. This part of the project serves as an introduction to what spatial cognition is as a whole, the different ways of understanding spatial cognition, and how it can be investigated and understood in order to find a way of improving assessment and rehabilitation of visuospatial cognition. Are there any problems with the current methods of assessment and rehabilitation?

3.1 Spatial cognition overall

Spatial cognition in itself is the large and diverse study of human behaviour connected to our ability to perceive, navigate, interpret, mentally represent and interact with spatial characteristics of our environment (Waller and Nadel (2013) pp. 3-5). It includes relations between objects such as orientation, location, distance, direction and what an object actually is, through size, shape and scale (ibid.). Potentially, spatial cognition utilizes all mental processes such as attention, perception, memory, categorization, language and problem solving (ibid.). The use of so many different areas of psychological processing makes the field of spatial cognition very diverse and it is relevant to many fields of science (ibid.). Nearly all human behaviour involves spatial cognition, whether it is finding a car in a crowded parking lot, reading a map or navigating in an unfamiliar city. Spatial cognition is also involved in human behaviour, which is not connected to navigation. It is also related to memory, and the distinction and recognition of different objects and their relation to ourselves, such as remembering certain features of a statue, or the alignment of a picture frame comparative to the wall it is hanging on (ibid.). This means that spatial cognition is not only our ability to place ourselves in relation to objects, but is also the ability to place and relate objects to one-another in the world around us.

3.2 Environmental scales: small, medium and large

One way of understanding spatial cognition is to scale the world around us, or environmental scale. A small-scale space does not necessarily mean a small physical space, but is rather a space, which takes little effort or action to understand, such as simply moving your eyes or your head (Waller and Nadel (2013) pp. 4-11). An example could be reading a paper or looking at a computer screen, but a very large physical space could be perceived as a small-scale space, if looked at from a plane (Waller and Nadel (2013) pp. 4-11, Montello (1997) pp. 312-314, Tversky (2003) pp. 66-69). A medium-scale space on the other hand requires more effort to understand, and could be spaces such as a room or a small forest clearing. While the objects and the outline of the space surrounds us, it takes little locomotive effort to orient ourselves in the space, however it may involve us moving our head more or turn our entire body in order to scan the space and the objects within (Waller and Nadel (2013) pp. 4-11, Montello (1997) pp. 312-314, Tversky (2003) pp. 69-72). A large-scale space requires a lot more locomotion to orient ourselves in. It could be cities, large forests or entire buildings, because it is impossible to completely understand the outline of, for instance, an office building, without moving around in it and observing and categorising the different rooms (Waller and Nadel (2013 pp. 4-11, Montello (1997) pp. 312-314, Tversky (2003) pp. 72-77). According to Montello (1997), this is just one way of classifying space, as well as the classification created by Zubin (1989), in which he classifies *"A"* as spaces smaller or equal to the size of the observers' body, such as pencils and paper, and can be manipulated (Montello (1997) pp. 313-316). *"B"* are larger than the observers' body, but can be viewed from a single viewpoint, such as trees or the outside of a house, but cannot be manipulated (ibid.). *"C"* can also be referred to as "scenes" and are larger than the human body, and need to be scanned to be investigated, which means that the eyes have to move across the "scene"; this could be a large room or a beach (ibid.). *"D"* are spaces much larger than the observers' body. Zubin (1989) refers to these as "territories", and they cannot be perceived as a unit; it could be an ocean, a forest or a large city (ibid.). Montello (1997) argues that space could be distinguished into four classes of psychological space: *Figural, vista, environmental and geographical* (ibid.). In short, "figural" space is projectively smaller than the body of the observer, which means that the space may not actually be smaller than the observer, but if it is seen from a distance it can be perceived from one place without the need to move (Montello (1997) pp. 313-316). He divides figural space into “pictoral” spaces, which are flat space, such as pictures and “object” spaces, which refers to 3D objects. “Vista” space refers to space the same size as the body or larger, which can be seen without moving (ibid.). This would be single rooms, horizons or town squares. “Environmental” spaces surround the body and require a lot of locomotion and time to comprehend. This could be buildings, cities or a forest if it surrounds the body (ibid.). “Geographical” spaces are much larger spaces, which cannot be fully understood by moving around it. In this case we use symbolic representations, such as maps, figures or models in order to reduce the geographical space to figural space (pictoral) (ibid.). Montello (1997) also argues that we reduce environmental spaces to figural spaces with maps and that drawing a map would draw more on our understanding of figural space than on environmental space (ibid.).

A traditional way of testing our psychological abilities in spatial cognition has been done with standardized pencil-and-paper tests, such as line bisections, line drawings of shapes that have to be rotated, folded or flipped in our heads (Waller and Nadel (2013) pp. 4-11). Some tests related to these standardized tests will be presented later in this project. The problem with the standardized pencil-and-paper-tests is that they are primarily focused on small-scale spaces, and relating the results and the human capabilities to medium or large-scale spaces poses some issues. According to Montello (1997), a primary problem with the standardized tests is, that they ignore the relevance of scale, when testing spatial capabilities in humans (Montello (1997) pp. 316-321). He argues that the pencil-and-paper-tests, as well as tests administered via a computer screen, primarily test pictorial spaces, and try to assess performance in environmental spaces such as navigation and landmark location, which he finds questionable (ibid.). It is estimated that these tests can only account for 10% of the variance in our large-scale navigation behaviour, and therefore lack ecological validity (Waller and Nadel (2013) pp. 4-11, Kozhevnikov et al. (2006) pp. 398-400). A lot of research has also been made on the medium scale space, where it has been investigated how people orient themselves in a room, remember where objects are located, what the objects are and how they move relatively to the participants of the experiment, and how to orient ourselves after disorientation (Waller and Nadel (2013) pp. 4-11)). The research made on large-scale spaces had been primarily focused on navigation. Navigation is a rather complex ability and require for humans to use landmarks, which is an object or a structure the person navigating uses in order to take appropriate action (Waller and Nadel (2013 pp. 4-11, Waller and Lippa (2007) pp. 910-912). The action taken is directional. An example could be a person driving towards a destination. On the way to the destination, the driver passes a church. The driver knows the church and knows to turn left when reaching it in order to drive in the right direction (Waller and Nadel (2013) pp. 137-147, Waller and Lippa (2007) pp. 910-912). The fact that the church helps the driver take the appropriate directional action to reach their destination makes it a landmark, and the use of landmarks is called piloting (ibid.). Apart from the landmarks we also use beacon following to find our way. Beacons are usually the actual destination or something close enough to the destination, that it makes sense to follow it or travel towards it (Waller and Lippa (2007) pp. 910-912). The ability to determine where we are based on information about the speed with which we move is called dead reckoning (Waller and Nadel (2013 pp. 11-14, 100-104). We use a more global representation of our environment to orient ourselves, which is called mental mapping, and is our ability to use a mental representation to recognize places and to imagine distances and directions (Waller and Nadel (2013) pp. 156-167), and the ability to follow a point of reference (beacon following) (ibid.).

3.3 Spatial processes: online and offline

A different way of organising spatial cognition is to differentiate between online spatial processes and offline spatial processes (Waller and Nadel (2013) pp. 4-11). Online processing is our ability to situate ourselves in the present moment, interpret and use spatial relationships such as distance and directions to solve problems or achieve immediate goals (Ibid.). Other abilities would be object recognition and distance perception, as well as spatial updating, where we update and re-evaluate our spatial representation as it changes through our movement (ibid.). Offline processing on the other hand involves long-term encoding, storage and retrieval of spatial information. These abilities are crucial to enable navigation, route planning and direction giving, since they primarily rely on our memories of our spatial environment (ibid.). An example could be an attempt to give directions to the local supermarket, even though we are unable to see it in the moment we are explaining the route.

3.4 Distance and direction: egocentric and exocentric space

A third way of organising spatial cognition is to focus on the spatial information itself. The most investigated spatial relations are the relationship between distance and direction (Waller and Nadel (2013) pp. 36-54). The specifications of distance and direction require an origin and a scale (not to be confused with the scale previously mentioned, but rather as a system of quantitative measurement such as the Celsius scale or measuring in centimetres (ibid.). When specifying an origin we may choose to focus on either ourselves, which can be described as self-to-object-distances (egocentric space), and is knowing how far away I am from a tree (Marsh and Hillis (2008) pp. 1215-1216). We can also focus on another object, which can be described as object-to-object-distances (exocentric space, but the synonym "allocentric space", will be used from here on out), which is knowing how far the tree is from a nearby rock (Waller and Nadel (2013) pp. 36-54, Marsh and Hillis (2008) pp. 1215-1216).

These different ways of organising spatial cognition are not contradicting; in fact they are often intertwined and are looked at as different facets of spatial cognition as a whole (Waller and Nadel (2013) pp. 4-11).

3.6 Ego- and allocentric space

One of the forms of representations the PPC is responsible for is the distinction between egocentric space and allocentric space (Waller and Nadel (2013) pp. 36-54, Marsh and Hillis (2008) pp. 1215-1216). Egocentric space can be categorised as spatial representations which relate directly to the body axis, and include the use of eye-centered, head-centered and arm-centered frames of references. Put in another way, the environment is represented in relation to a body part (ibid.). On the other hand, allocentric spatial representations use landmarks and objects in the environment, without using the body or oneself as a reference point. The allocentric spatial representations are very useful for navigation and spatial orientation (ibid.). These two types of spatial representation overlap when we orient ourselves in the world. Since we use memory for navigation, we need to use several egocentric views from different spatial viewpoints in order to code the relations between landmarks in our environment and between spaces to generate allocentric spatial representations (ibid.). The PPC generate both types of spatial representations, and it does so by using different spatial features. The egocentric spatial representations use self-motion cues such as balance for spatial orientation, for encoding transitional and rotational accelerations and proprioceptive feedback, which e.g. is the sensation of knowing where your arm/hand is in relation to your body, from muscles and joints, and visual cues such as linear and radial cues of optic flow (ibid.). Allocentric spatial representation on the other hand primarily uses information coming from the environment such as visual cues, smells, sounds and somatosensory cues such as temperature, wind and touch (Ibid.).

3.7 Spatial inattention and unilateral neglect

One of the most common ways of investigating spatial representations is to observe and test people who suffer from spatial inattention disorders such as spatial neglect, which can be caused by a lesion in the PPC (Waller and Nadel (2013) pp. 36-54). Spatial neglect is characterised by having deficits in responding to, reporting or orienting to stimuli in the environmental space contralateral to the patient's brain lesion (ibid.) (see 5.0). The awareness deficits these patients experience can be specific to personal space, peri-personal space or extra-personal space, but differ among the patients (ibid.). E.g. a patient may neglect the left half of their face, while looking in a mirror, but still respond to stimuli in external spaces, while a different patient may show neglect in the peripheral space, that is within reach, but fail to react to stimuli in spaces further from the body (ibid.). The most common cause of neglect is stroke.

3.8 Summary

Visuospatial cognition is large and diverse study of human behaviour and our ability to perceive, navigate, interpret, mentally represent and interact with the spatial characteristics of our environment. Nearly all human behaviour involves spatial cognition in some way, whether it is actual navigation through a crowded city, finding a car in a parking lot or remembering certain characteristics of objects we have encountered. There are several ways of understanding spatial cognition, and they should not be separated, but should rather be used as an overall basis for understanding how we navigate the world around us. One of the main ways is by scaling our world through environmental scaling. How this scaling is divided depends on which researcher is asked. It could be Zubins ABCD scale, Montellos scales in which he differs between pictoral space and object space divided onto vista-, environmental- and geographical spaces, or it could be the tri-part division of small, medium and large scale spaces presented by Waller and Lippa. The importance of taking environmental scales into account when testing our spatial capabilities, should not be underestimated, no matter which scale is preferred. Montello argued that the traditional pen-and-paper-tests cannot represent the real world since they fail to take scale into account. They primarily focus on pictoral space and attempt to make an assessment of our capabilities in navigation and landmark location. A different way of understanding spatial cognition is by differentiating between online- and offline processes, where online processes are linked to our ability to take action by situating ourselves in the present moment and update our understanding while the environment around us changes. Offline processes on the other hand are more linked to our memory, where we can plan routes to get to a destination without actually being on our way there. Another way of understanding spatial cognition is by focusing primarily on the actual spatial information. Space can be divided into Egocentric- and Allocentric space, where egocentric space represents the space which is directly in relation to the body axis, while allocentric space represents the space between objects in our view. While the two types of space use different cues, they often overlap. The most common way of investigating spatial cognition is to test people with spatial inattention. Spatial neglect is a good candidate for a syndrome, where eye-tracking and virtual reality could be useful for assessment and rehabilitation. Spatial neglect is a common consequence of strokes, and therefore it could be useful to understand the underlying causes and mechanisms of stroke.

4.0 Stroke

Stroke, or apoplexy, is the second most common cause of death in the western world (Lezak et al. (2012) p. 229, Guzik and Bushnell (2017) pp. 15-17), however the prevalence and mortality of stroke in America has been decreasing by up to 40% in the past 30 years, and it has also decreased in other high-income countries (Guznik and Bushnell (2017) pp. 15-17). In Denmark alone it is estimated that 12,500 – 15,000 people suffer from a stroke annually (www.sundhed.dk). Strokes were defined by the World Health Organisation (WHO) in 1989 as: *"The rapid development of clinical signs of focal or global disturbance of cerebral deficit lasting 24 hours or longer, with no apparent cause other than vascular origin"* (Lezak et al. (2012) p. 229, Cook and Tymianski (2014)

p. 15). If the cerebral deficit lasts less than 24 hours it is classified as a “transient ischemic attack” (TIA). Unlike a heart attack the stroke is usually painless, which often causes victims to avoid medical attention and wait for the symptoms to subside. However, in recent years, awareness of symptoms in the general public on the urgency of immediate medical attention, and the use of tPA (tissue plasminogen activator), has reduced the mortality of a stroke, if administered within the first few hours following an acute stroke (Lezak et al. (2012) p. 229, (Stemer and Lyden (2010) pp 29-33, Su et al. (2009) pp. 155-157, Reddy and Hart (2014 p. 12). Estimations suggest that up to 150 out of every 100,000 person suffer from strokes. While this seems to have been a stable estimation, the number of strokes worldwide seems to be increasing. A reason for this could possibly be better diagnostic techniques, since some strokes have no immediate effect on the victims, and remains unnoticed until detected using neuroimaging techniques (ibid.). While strokes can happen to anyone, it mostly occurs in the elderly population, where some estimate that 85-90% of stroke victims in Denmark are 60 years of age or above (www.sundhed.dk). Therefore we might experience a further increase in the prevalence of strokes, as the population above 60 years of age is becoming an increasingly larger percentage of the general population.

4.1 Common Causes

There are several factors, which may influence the risk of having a stroke. Some risk factors are connected to lifestyle and diet, such as smoking, drug and alcohol abuse, obesity, fatty and sugar rich diets, lack of physical activity (Lezak et al. (2012) p. 230, Guzik and Bushnell (2017) pp. 17-35, Reddy and Hart (2014) pp. 8-10). Others are associated with other diseases such as diabetes, hyperlipidemia, hypertension, inflammatory diseases and cardiac diseases (ibid.). Hormone therapy is also a contributing factor as well as female oral contraception (ibid.). The risk of having a stroke rises exponentially with age, as mentioned above, and hypertension is the main cause. In 2016 there were 4185 cases of stroke in Denmark in the age group of 67 and above (http://www.statistikbanken.dk/aed20). Fatty acids, high levels of cholesterol, smoking and diabetes causes thickened arterial walls, which causes most strokes (ibid.).

4.2 Pathophysiology

A stroke is, as defined in the above, a focal or global disturbance of cerebral deficit, with no other apparent cause than vascular origin (Reddy and Hart (2014) pp. 5-8). The main feature of a stroke is the disruption of blood-flow to the brain. Blood carries nutrients such as glucose and oxygen to the brain, and when the blood-flow is disrupted, the nervous tissue of the brain is deprived of oxygen and quickly begins to die (Lezak et al. (2012) pp. 229-230, Reddy and Hart (2014) pp. 10-12). This is why the symptoms of a stroke develop rapidly, and irreversible damage is caused. The area of tissue that has been denied nutrients due to a disrupted blood-flow is called an infarct, and the process of tissue damage due to loss of or disrupted blood-flow is called infarction (ibid). Most strokes are ischemic infarctions, and are caused by tissue starvation due to a disturbance in the blood-flow. Some infarctions, but few, are caused by absence of or insufficient nutrients in the blood (ibid.). The tissue surrounding an infarct, and the functionally connected areas are at risk as well. The dying tissue in the infarct causes neurochemical changes and may eventually cause the surrounding tissue to die, and become part of the infarct, and therefore part of the area in which there is irreversible damage (ibid.). There are treatments available for victims of stroke, if administered within a few hours. Thrombolytic therapy can break up particles such as fat or calcium in the blood and can help the blood flow more freely. It is most effective within the first 4 1/2 hours after the stroke occurred; however hemorrhage is a risk when used (Lezak et al. (2012) pp. 229-230, Stemer and Lyden (2010) pp. 29-33, Su et al. (2009) pp. 155-157).

4.3 Haemorrhagic Strokes

There are two common subtypes of stroke. Haemorrhagic strokes are the most deadly of the different types of strokes, with a mortality rate of between 35-50% within 30 days of the stroke occurring (Lezak et al. (2012) pp. 234-235). The most common cause of a haemorrhagic stroke is hypertension, but chronic anticoagulants can also increase the risk of haemorrhage (Guzik and Bushnell (2017) pp. 17-21). Often the cause is ruptured aneurism, malformation of an artery, tumours or deficient coagulation (Lezak et al. (2012) pp. 234-235, Cook and Tymianski (2014) pp. 24-28). As mentioned earlier, the risk of a stroke rises with age, and that is also the case with haemorrhagic strokes caused by hypertension, where the most common victims are between 60 and 80 years of age (ibid.). Haemorrhagic strokes tend to be subcortical, since the rupture of arteries often happens at the base of the cerebral hemispheres, and therefore they often only affect the brainstem, the thalamus and the basal ganglia (ibid.).

4.4 Ischemic strokes

Ischemic strokes are the most common among new strokes, and are caused by a blockage of a blood vessel, and there are different kinds of blockage (Lezak et al. (2012) p. 231, Cook and Tymianski (2014) p. 16). The most common is cerebral thrombosis, which is a build-up of thrombic or fatty deposits in the walls of the artery, and are the cause of 60-70% of all strokes and make up 75% of all ischemic strokes (ibid.). These obstructions are called “thrombus” or “blood clots”, and form most commonly where the blood vessels branch. When the clots begin forming, they narrow the passageway or close the vessel completely (ibid.). It can occur suddenly, and often develop fully over the course of half an hour, and in 1/3 of cases, it develops for hours or even days. About 80% of victims of this type of stroke improve quickly as swelling resolves and metabolism is resumed, but about 50% are still left disabled, and improvement is relatively small after three months after the stroke (Lezak et al. (2012) p. 231).

The other type of ischemic stroke is the cerebral embolism. The cerebral embolisms are also blood clots, but are not formed, where they obstruct the blood flow. They are not commonly formed by lesions in the main arterial vessels to the brain, but are more commonly formed in the heart and its blood vessels. They may consist of thrombotic material, fatty substances, clots of bacteria or gas bubbles (see fig. 1). Most commonly this type of stroke is abrupt and without warning (Lezak et al. (2012) pp. 231-232, Cook and Tymianski (2014) p. 16).

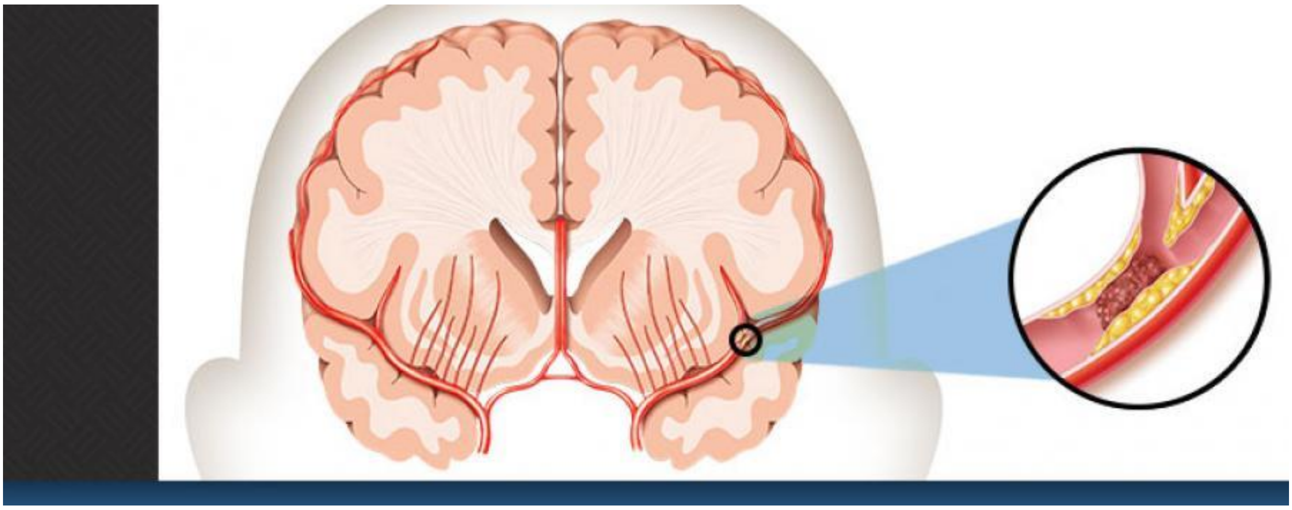

Fig. 1. An ischemic stroke caused by a blockage in the artery

Reprinted from The National Stroke Association website http://www.stroke.org/understand-stroke/what-stroke

Ischemic strokes can produce large artery infarctions, which can result in significant behavioural changes, either by cortical injury or by disruption of larger subcortical areas (Lezak et al. (2012) p. 232-234). Even small infarctions can result in significant changes if several of them occur at the same time and create an increasing volume of damaged tissue. Even though the effects of ischemic strokes can be very varied depending on area and depth of which they occur, they have a tendency to have lateralized effects (ibid.). They can occur very quickly and the symptoms are quite clear acutely, but are less defined over time. At first swelling and other side effects of the stroke may cause the symptoms to be more bilateral and increases the mortality, but once these effects wear of, and the brain returns to a more normal state, the bilateral symptoms decrease and the lateral effects become clearer (Lezak et al. (2012) p. 232-234). Common consequences of the ischemic stroke are aphasia, hemiplegia and perceptual deficits (Bartholomeo (2014) pp. 21-24). Hemiplegia and perceptual deficits, such as inattention, often occur simultaneously (ibid.). Patients with a left-sided infarct commonly have speech and language disorders, while patients with right-sided infarcts often suffer from perception- and visuospatial deficits, such as left-sided neglect (ibid.). Right-sided neglect does occur, but left-sided neglect is more common. Emotional effects of ischemic stroke are depression, regardless of which side of the brain was affected, while right-sided infarcts seem to result in apathy, and left-sided infarcts seem to cause catastrophic thinking, which could suggest that patients with different affected hemisphere may experience depression differently (ibid.). It is also interesting to note that patients with right-sided infarcts tend to develop depression more frequently post-hospitalization, than left-sided infarcts (ibid.). A general decrease in physical activity and social-behaviour is common with stroke patients. The lack of physical activity could be made difficult, especially for patients with hemiplegia, while depression could be an important factor when patients avoid social activities (ibid.).

4.5 Summary

Strokes are the second most common cause of death in the western world and in Denmark up to 15,000 people suffer from a stroke annually, but it is decreasing in western world countries. Strokes primarily occur with the elderly population, and in Denmark 85-90% of all stroke victims are above the age of 60. There are many causes of strokes, both related to lifestyle and to different diseases, but the main cause is hypertension. Strokes can be divided into two categories, the haemorrhagic strokes and the ischemic strokes. Haemorrhagic strokes are caused by the rupture of blood vessels, often due to tumours or aneurisms, and while deadliest, it is the less common of the two types. Ischemic strokes are the most common and are caused by an obstruction in a blood vessel. They can either be thrombotic or embolic. A common consequence of ischemic strokes is spatial neglect. Right-sided neglect occurs but is less common than left-sided neglect. Now that the common underlying cause of neglect has been established, it is possible to move on to the syndrome itself and it symptoms.

5.0 Spatial Neglect

When patients experience stroke in the right posterior hemisphere, one of the most commonly seen disorders is “spatial neglect” (or unilateral hemispatial neglect, hemi-neglect, visuospatial neglect or unilateral neglect) (Lezak et al. (2012) pp. 78-79). The syndrome is seen in 40-90% of patients in the acute phase after stroke (Danckert (2014) p. 71, Kortman and Nichols (2016) p. 344). Patients exhibiting this syndrome suffer from an impairment of attention to and awareness of stimuli in both personal and extra-personal space, and is most commonly seen on the left side (Lezak et al (2012) pp. 78-79, Danckert (2014) pp. 71-74, Karnath and Rorden (2008) p. 2, Kortman and Nichols (2016) p. 344)). The eyes and primary visual system are fully functional, and yet the patients may have difficulty or complete inability to acknowledge or attend to events on the contra-lesional side of space, and often they are completely unaware (ibid.). This includes the inability to sense their own limbs, visual input or auditory input, although few exhibit all symptoms at the same time. In the late 1980's Vallar and Perani identified that the area most commonly damaged when this syndrome occurred was the parietal lobe, but the area around the central sulcus may also be involved as well as the temporoparietal cortex (Lezak et al (2012) pp. 78-79). The condition ranges from mild attention deficits on the contra-lesional side of their injury, to severe attention deficits, where the patients lose the ability to orient themselves and/or report to stimuli on the contra-lesional side of their injury (Suchan et al. (2012) pp. 1136-1138, Halligan et al. (2003) pp. 91-93). The condition can become evident in several ways. When it is mild it can be fairly discrete and only apparent to the examiner. A way of detecting it could be double simultaneous stimulation, where the examiner lightly touches both cheeks or wiggles a finger on each side of the periphery of the patient's visual field of view. Patients may be unable to sense the actions taking place on their contra-lesional side when it happens simultaneously, but are able to acknowledge it when presented with the stimuli one at a time (Lezak et al. (2012) pp. 80-81). Patients with mild inattention to their own bodies may seem as if they are simply not paying attention to their left side. They may only use their right pockets, or bump into things on their left side, while patients with severe inattention be completely unaware of the existence of the left side of their personal space. In some extreme cases, the patients deny ownership of their own limbs, if the limbs are brought to their attention (Bartholomeo (2014) pp. 50-53). Patients with visuospatial inattention may not only have issues detecting and reporting on their own bodies, but may also have problems with drawing and/or copying a figure, when it is presented to them. They often ignore the left side of a figure when copying it, or flatten or diminish the figure in a spontaneous drawing (see fig. 2). The more complex the drawing, the more apparent the condition becomes (Lezak et al. (2012) pp. 80-81).

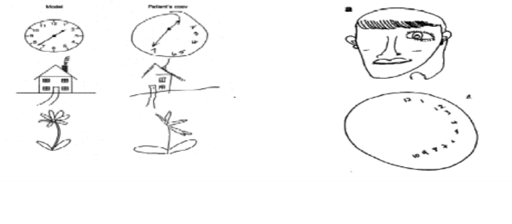

Fig.2 reprinted from https://tactustherapy.com/what-is-left-neglect/

When copying a text, the patient may omit words or numbers to the left, even though the finished text may be nonsense. Left visual inattention is often seen in combination with left visual field defects, but not always. Patients with obvious left-sided visual inattention do not seem to scan the left side of their visual field, even when spoken to from the left side. These are the ones that will start reading in the middle of a sentence, instead of reading from left to right. This would make most texts nonsensical and most patients stop reading at their own accord due to “loss of interest”, although they may be able to read normally when guided from left to right (Lezak et al. (2012) pp. 80-81).

5.1 Assessment of neglect

In the above, a few methods of neglect assessment are mentioned. In this paragraph a few more commonly used examples of assessment methods will be accounted for. Firstly, the “bedside tasks” will be mentioned, then “cancellation tasks” will be presented.

5.2 Bedside tasks

In “the clock drawing test”, the patients are asked to fill in the numbers of a clock in a circle of 8 cm in diameter. 1 point is scored for the wrong positioning of 3, 6, 9 and 12 and 1 point total for any of the other numbers. Patients with severe neglect have a tendency to draw all numbers on only one side of the circle as seen in fig. 3:

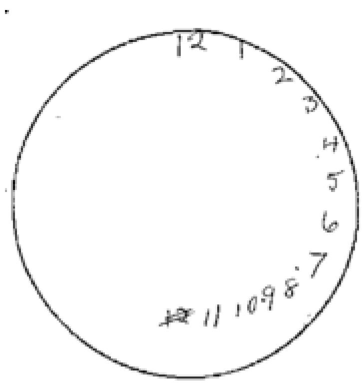

Fig. 3 reprinted from http://www.ganfyd.org/index.php?title=Clock_test

A second bedside task is the “Copying Task”. The patient is asked to copy a figure or a drawing, and by the quality of the copy, the neglect syndrome can be scored. The copies are scored by omission of features or entire figures, and additional points are scored when e.g. left sided figures are drawn on the right side.

5.3 Cancellation tasks

Cancellation tasks are also fairly common when assessing the neglect syndrome. A common cancellation task is “the letter cancellation task”. Various letters are distributed on a piece of A4 paper, and on each side of the paper, there are 30 “A’s”, making it a total of 60. The patient is asked to cross out all of the A’s on the paper, and is then scored by how many they cross out, and the maximum score is 60. The “Star Cancellation task” and the “Line Crossing task” are based on the same principle, but with stars in different sizes, a number of lines, randomly distributed across a piece of paper, where the patient is asked to cross out all the lines. The “Bells test” can consist of 7 columns with 5 targets in each, in this case “bells” and 40 distractors, but the numbers of distractors and targets can vary, depending on which version of the test is used (Ferber and Karnath (2001) pp. 599-603). The columns are distributed so as one of the columns are in the middle of the paper, with 3 columns on each side. The patient is tasked with crossing out all the targets. An example can be seen in fig. 3.

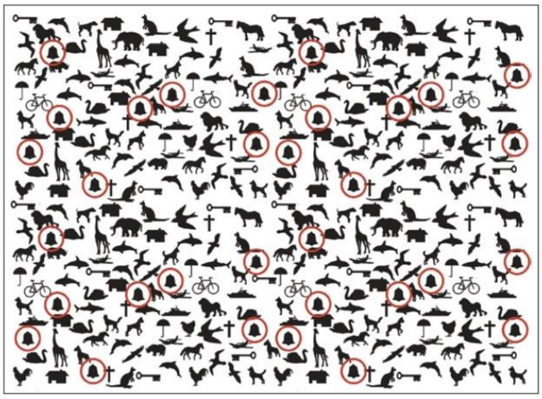

figure 3 reprinted from https://quizlet.com/169752379/adult-ei-final-study-guide-flash-cards/

A task used for assessment is the “baking tray task”. In this test, the patient is presented with a tray or a blank surface, on which they are asked to distribute 16 identical objects evenly across. When scoring this test, the correct distribution of 8 objects on each side is measured. The highest score is the correct distribution of 8 on each side. Patients with neglect will have difficulty distributing the objects evenly on their contra-lesional side, or simply placing them on the left side. An example can be seen in fig. 5

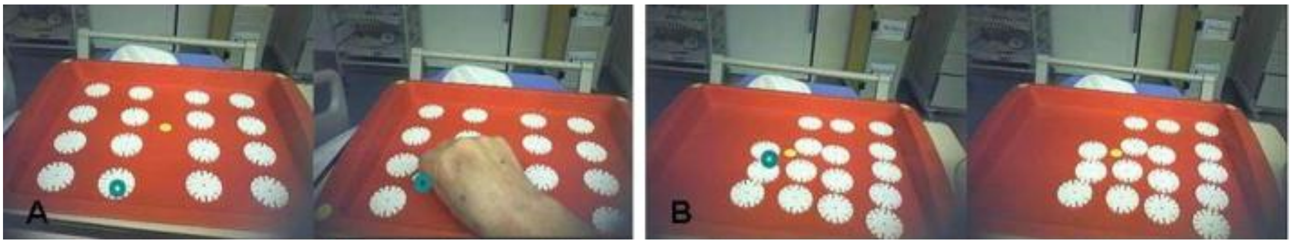

fig 5 reprinted from https://www.sciencedirect.com/science/article/pii/S138824571500440X

5.4 Line Bisection Task

In the “line bisection task” the patient is asked to mark the point on a number of lines, which divide each line into 2 equally long halves. Each line is horizontally oriented. In order to avoid having the patient place the divide based on the centre of the page, the centre of the lines can be placed at different horizontal points of the page, or with the right end of the line corresponding to the right margin of the sheet of paper. The deviation of the mark the patient places, from the true centre of the line is measured and left side deviations are marked as negative deviations and right side as positive deviations. The length of the deviation is then divided by the length of the actual centre of the line, and is then multiplied by 100 to give a percentage score where right side deviation is a positive percentage and the left side deviation is negative. An example of the test can be seen in fig 6.

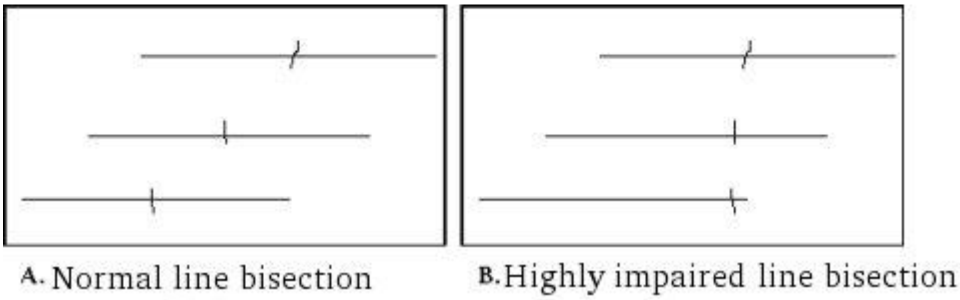

fig. 6 reprinted from https://www.strokengine.ca/en/indepth/lbt_indepth/

5.5 Validity of assessment tasks

In a series of tests done by Ferber and Karnath (2001), it was attempted to measure the validity and effectiveness of different classic neglect assessment tasks (Ferber and Karnath (2001) pp. 599-606). They found that the tests are not equally effective. They administered the tests mentioned in the above on 35 patients, who had well-defined neglect. The line bisection task missed 14 out of the 35 (40%) well-defined patients, while the bells cancellation task missed only 2 (6%) (ibid.). In their study, they found that the bells cancellation task and the stars-cancellation task are more reliable methods for diagnosing neglect than other commonly used tests (Ferber and Kanarth (2011) pp. 599-606). This could create a basis for a discussion on the sensitivity and specificity of the traditional pen-and-paper-tests. If the line bisection task missed 40% of a sample of patients with well-defined neglect it has a low sensitivity and a high specificity. The cancellation tasks mentioned in this paper seemed to have a high sensitivity when they missed only 6% of the participants, but how would it fare with participants who does not have well-defined neglect, and instead has more subtle symptoms? Perhaps a larger percentage of patients would be missed (Ferber and Kanarth (2001) pp. 599-606).

A different issue with these tests could be the question of ecological validity. It could be argued that the cancellations tasks, drawing tasks and line bisection tasks, tell us little about how the patients fare in their everyday lives (Kortman and Nicholls (2016) pp. 345-346). They rely on immobile targets, and do not take moving distractors or the distracting sounds of everyday life into consideration. One could argue, that in the everyday lives of the patients, moving distractors, targets and sounds could have a big influence on how the patients navigate in a setting such as traffic, cooking and shopping. Even subtle signs of neglect, could be important to measure, to assess risk of accidents or other safety concerns for the patient.

5.6 Summary

Spatial neglect often occurs when a patient has a stroke in the posterior hemisphere, and is most commonly seen with right-parietal lesions. Most commonly the patients suffer from neglect on their contralesional side of their stroke. The condition ranges from mild attention deficits, where the patients are unable to orient themselves and/or respond to stimuli on the contralesional side of the stroke. Patients may only pay attention to the non-neglected side and only use pockets, shave or get properly dressed on that side, while bumping into things on the neglected side. In some cases the patient is completely unaware of what is happening on the neglected side, including their own body parts. There are several ways to test neglect available, which are widely based on traditional pen-and-paper-tests such as the clock drawing test, copying tasks, cancellation tasks and line bisection tasks. There are issues with these tests and they have been criticised for not being sensitive enough, which means that neglect patients with mild neglect sometimes are missed by the tests, and for lacking ecological validity. Virtual reality and eye-tracking could possibly help improve on these issues.

6.0 Rehabilitation of spatial neglect

As presented in 5.0, spatial neglect is a complex syndrome, and the patients exhibit not only visual defects, but tactile defects as well. Even though some of the symptoms of some patients fade or disappear completely after the acute stages of a stroke, in some patients the subtle symptoms persist or are still severe even a year after their stroke-incident. This makes the syndrome fairly diverse and it makes treatment difficult. In this part of the project, common rehabilitation treatments currently available will be presented and evaluated.

6.1 Visual exploration therapy

Visual exploration therapy (VST), is an older method of rehabilitation treatment available to neglect patients, and is developed by Diller and Weinberg in 1977 (Kerkhoff and Schenk (2011) pp. 1072-1073). Essentially, in this method the patients are presented with a flat surface displaying several items. The patients may then be asked to describe all items on the surface or asked to locate a specific item among a number of distractors (ibid.). Today there are many versions of the VST, varying from versions made on big, home cinema-like screens, computer displays, displays the size of magazines, and may differ in the way instructions are given and in the method of presentation (Kerkhoff and Schenk (2011) p. 1073). This treatment is to be repeated with a minimum of 40 sessions.

According to Kerkhoff and Schenk (2011), there are some important issues with this method of treatment. One key issue is the issue of specificity, since the VST seems to improve on visual field defects, and seems to improve visual scanning and tasks such as line bisection (see 5.4) and reading, however it does not seem to improve non-visual neglect (Kerkhoff and Schenk (2011) p. 1073). It improves on visual search and reading, but not tactile search. Apart from that, it is a rather time consuming treatment since the minimum of 40 therapy sessions take 50 minutes each, if stable results are to be found (ibid.). This demands a lot of commitment from both the patient and the therapist, which can be challenging since patients regularly suffer from a lack of insight into their syndrome (ibid.).

6.2 Optokinetic stimulation therapy

Optokinetic stimulation (OKS) uses the way we orient ourselves in our world. If we are looking at a visual display that fills our entire field of view, and it moves to the left, we feel as if our body is rotating to the right. We try to compensate to this by re-orienting ourselves to the left. This phenomenon is exploited in this method of rehabilitation therapy, since it could counteract the orientation bias in neglect. According to Kerkhoff and Schenk (2011), this method has proven to be quite effective, and grants a significant reduction in neglect symptoms. Kerkhoff himself tested this method in a pilot study in 2002 on three patients, who underwent VST 3 times a week throughout the study and for 2 weeks they were simultaneously subjected to various neglect assessment tests, to rule out spontaneous improvement or improvement due to test repetition. During this period, there were not improvements to the patients even though they went through VST. After this they underwent 5 OKS-training sessions within 14 days. After the OKS training, there was significant improvement to auditory neglect and neglect dyslexia as well as significantly improved cancellation performance, and the improvement were stable after 2 weeks in a follow-up study. The pilotstudy was later repeated in other studies and the positive results seemed to persist, except for one study done by Pizzamiglio et al. in 2004. In the other studies, including the pilot study from 2002 by Kerkhoff, pursuit eye movements where encouraged. In Pizzamiglios study however, it was discouraged, and the positive result were not found. This promotes the idea, that pursuit eye movements are important to OKS-training.

Overall this method seems to be effective and useful in the rehabilitation of neglect patients. However, just as the VST it is a rather time consuming method of therapy which demands patients to be actively participating to some degree, and it suffers from some of the same specificity problems as VST, since it does not seem to improve significantly on tactile neglect (1073-1074).

6.3 Neck-muscle vibration therapy

This method of neglect rehabilitation uses fairly the same phenomenon as the OKS. Apart from our visual field, we also use proprioception to orient ourselves in the world. When using neck-muscle vibration therapy (NMV), we exploit phenomenon that we experience looking straight ahead when our neck muscles on either side are stretched to the same extent. By applying vibration to the neck muscles on one side, it is possible to create an illusion of constant movement towards that side. In a case of left-sided neglect vibration is applied to the left side. It gives the patient the impression that their head is moving towards the left, and additionally it gives the impression that the trunk is moving toward the right, but how it is reported depends on the experimental setup. If the trunk is fixed, patients report that their head is moving, and if the head is fixed, patients report that their trunk is moving. The illusion is present as long as the vibration stimulation is active. Both experimental setups counteract the orientation bias and reduce neglect symptoms. Unfortunately, few studies have been made on the stable benefits of this treatment. In the studies made, it does seem that the NMV is effective on its own, but also in combination with VST. It is reported that the treatment has a positive effect on particularly tactile neglect, where improvements are seen in grasping, reaching, dressing and movement from bed to wheelchair and vice versa.

6.4 Caloric- and galvanic-vestibular stimulation

Caloric-vestibular stimulation (CVS) uses either cold water stimulation on the ear on the contralesional side of e.g. a stroke or warm water stimulation on the ipsilateral side of e.g. a stroke. CVS reduces sensory neglect as well as improves balance, awareness of hemiplegia, disturbances in the body scheme, improves deviation of the visual subjective straight ahead and somatosensory neglect symptoms (Arene and Hillis (2007) pp. 258-260). Galvanic-vestibular stimulation (GVS) on the other hand, uses small electrical impulses from electrodes placed behind the ear of the patient, and it produces the same improvements of neglect symptoms as the CVS.

Both are easy to administer and as long as safety guidelines are followed when using GVS, the methods are also safe. The improvements are noticeable in 10-15 minutes, which makes this method much more time efficient compared to the previously mentioned methods. However, few studies of the long-term effects of CVS and GVS have been made (74-75).

6.5 Prism adaptation

Prism adaption uses wedge prisms, which shifts the view on one side slightly. It can be used to correct the orientation bias in neglect patients (Arene and Hillis (2007) pp. 260-261). The patients are asked to wear the prisms and then point to a visual target. They will find that the hand they are pointing with is shifted to the side the prisms are wedged to. Since they can see their hand, or at least some of it, they will correct where they are pointing and over time, after 50-60 movements in the direction of visual targets, their ability to point at the target while wearing the prisms will improve (Azouvi et al (2017) p. 192). Once this adaptation period is over, the prisms are removed, and the patients are asked to point towards a target, but this time, they are unable to see their hand. This creates a before/after-prism effect, and they will constantly point to the formerly wedged side of their target. Another way of using this effect is to go through the adaptation period and then ask the patient to close their eyes and point towards, what they perceive to be, straight ahead. The patients perceived straight ahead direction will then have shifted towards the prisms wedged side.

This method is fairly easy to administer and require little and inexpensive equipment, and it is a non-invasive method (Azouvi et al (2017) p. 192). However, it seems as if the method has longer lasting effects if repeated often, 4-5 sessions a week lasting 50 minutes each for 8 weeks which makes it just as time consuming as VST- and OKS training (Kerkhoff and Schenk (2012) p. 1075).

6.6 Combination therapy

According to Kerkhoff and Schenk (2012), the tests presented and evaluated above, can in some instances be combined and have beneficial outcomes. They argue that matching the treatments with the specific symptoms of the patient could create a superior outcome. An example of this could be combining NMV with VST or prism adaptation, which yield superior results to NMV alone. By combining the two, it is possible to add the tactile component of NMV to the visual component of VST. Another option could be to combine VST with OKS, which also gets better results than VST standing alone. Again, in this case a tactile component of the OKS is combined with the visual component VST (Kerkhoff and Schenk (2012) pp. 1075-1077, Azouvi et al. (2017) pp. 192-195)

6.7 Summary

Neglect is a complex syndrome, which can be difficult to find the correct treatment. 5 different types of rehabilitation methods are presented. The VST seems to improve visual defects, scanning and tasks such as the line bisection task, but does not seem to improve on non-visual neglect. It is time consuming and demands a lot of commitment from the patient and the therapist. OKS seems to be effective, but just as the VST it does not improve significantly on tactile neglect. NMV seems to have a particularly positive effect on tactile neglect, and could be used in combination with VST. The CVS and GVS are easy to administer and are cheap. The effects are clear for 10-15 minutes, but further study is needed on the long-term effects. Prism adaptation is easy to administer and is non-invasive. However, it is also a rather time consuming rehabilitation treatment. It is advised not to use only one of the therapy methods, but to try and combine them, so that the treatments suits the particular case. While time consuming, virtual reality and eye-tracking could possible improve on VST, OKS and prism adaptation.

7.0 Useful Field Of View-test:

(Mazer) Automobile driving is 90% visual input.

The Useful Field Of View-test (UFOV) is a test, originally developed by Ball and Owsley (1993). The test was originally developed to assess the driving capabilities of the elderly. Previously, the driving capabilities of the elderly had been based on visual tests and questionnaires, where the elderly had to report on their own abilities and difficulties. Ball and Owsley (1993) criticised the dependency of questionnaires and had reached two conclusions*: "1) older adults report visual difficulties that are not adequately identified by standard clinical measures and 2) older individuals are sometimes totally unaware of their visual problems"* (Ball and Owsley (1993) p. 72). They criticised that the previous tests, which were supposed to assess driver capabilities in older adults, tested acuity in a setup, which had optimal conditions for the participant. The conditions had high contrast, high illumination, isolated static targets and no distractors that could diverge attention from the task at hand (ibid.). They argued that everyday life is nothing like the laboratory conditions, and that the tests lacked ecological validity. In everyday life, the driver has to pay attention to constant change in illumination, speed, changing environments (ibid.). The driver often has limited time to observe the environment and often have to make decisions on what to look at without knowing exactly what to look for. The UFOV seeks to measure reaction times to several distractors within the participant's field of view (Vance et al. (2006), (Wood & Owsley (2014). It is ecologically valid and has the ability to accurately predict risk of car-crashes and other mobility outcomes in adults. It does so by testing process speed (how fast can a participant react to targets in their peripheral vision), divided attention (how well can the participant locate peripheral targets, when there is an increased demand on their foveal vision and selective attention (how well can the participant localize a target imbedded in the condition contra how well they do it when the target is isolated) (Ball and Owsley (1993) p. 75). Ball and Owsley (1993) argue that the UFOV measures *"the window of attention within which an individual can be rapidly alerted to stimuli"* (Ball and Owsley (1993) p. 74). If a driver sees something that is noticeable enough to pay attention to, even in the peripheral view, the driver will naturally slow down and get more visual information about the thing. A driver with difficulty paying attention and restrictions in the visual field may not notice a hazardous stimulus and is more likely to crash the car. Fig. 7 illustrates the relative reductions of the UFOV in different people.

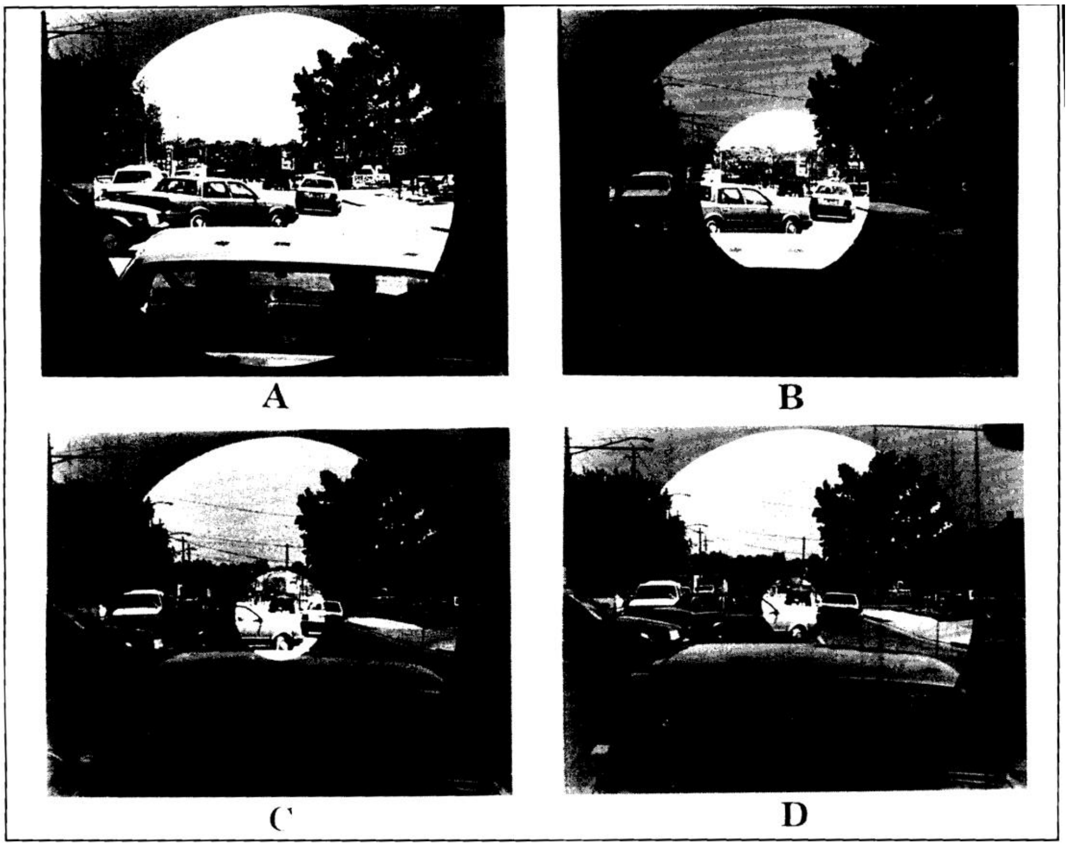

Fig. 7. Panel A represents the average driver. Panel B shows a severe reduction in processing speed of visual information and has a reduction of 50% in the UFOV. Panel C represents participants who are extremely sensitive to distractions and reacts slowly to them. Panel D represents participants who are either sensitive to distractions and reacts slowly to them and are unable to divide their attention between their attention between tasks in the periphery and their centre view (Ball & Owsley (1993) p. 75)

Performance on the test is correlated with mental status and several neuropsychological measures, so it does not rely solely on the visual-sensory information (Edwards et al. (2006) pp. 531-541). Apart from the ability to accurately predict risk of car-crashes, by assessing reaction times, and the functional peripheral vision of participants, it has also been used to assess the driving capacity of stroke patients (Mazer et al. (2001) pp. 553-557). Mazer et al. (2001) attempted to use the UFOV as an assessment tool for patients with stroke. They theorised that patients with right-sided lesions would perform poorer in the visual attention tasks, but they found no significant differences between the side of the lesion using UFOV. The UFOV can be administered with a personal computer, since the actual tests are performed via a computer monitor (illustrated in fig. 8) (Edwards et al. (2006) p. 531-541).

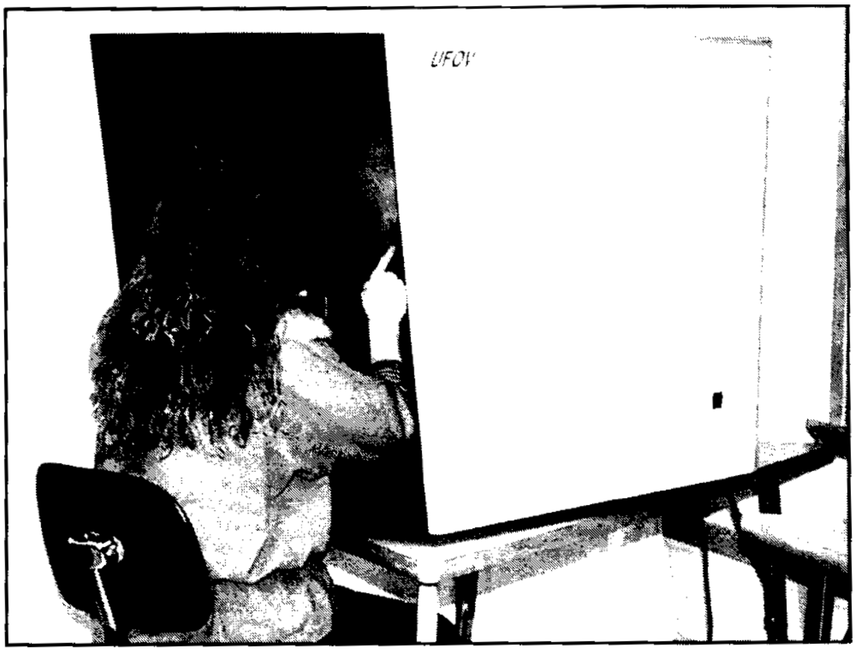

Fig. 8. The Ball and Owsley screen setup called the Visual Attention Analyser, with panels covering the peripheral vision, so as to avoid distractions from the environment outside the test. (Ball and Owsley (1993) p. 76)

8. Eye-tracking

Eye-tracking is a method with which it is possible to trace the gaze-patterns of an individual. By tracking the movements of the eyes, the eye-tracker can monitor what an individual is looking at and for how long. It does so by monitoring the small quick shifts the eye does called "saccades", and "fixations" (Conklin et al. 2018) pp. 15-33). When we read a text, or investigate anything within our field of view, our eyes do not glide across it, but do so in tiny abrupt shifts. Usually the shifts are so quick, that we are unable to gather important information from the text we are reading or the scene we are looking at (ibid.). When something of interest is focused the eyes pause to scan the thing being looked at. These pauses are called fixations. It is when fixations happen, that important information about what we are looking at, is obtained and processed (ibid.). When the information of the fixation is being processed, the saccades resume until the next point of interest is fixated upon. When reading a text, the eyes often perform "regressions" where the eyes move backwards in the text if we find that we have overlooked something important (ibid.). These eye movements and processes happen largely automatically and therefor researches have a chance to observe a largely unconscious behaviour in participants. Interesting variables that can be extracted from the gaze-date include: Saccade duration and length, as well as monitor fixation points or area, the amount of times that point is fixated on and the duration of the fixations (ibid).

8.1 Types of eye-trackers

There are different types of eye-trackers available for research, and they have different qualities, which are important to take into account, when deciding which to use for at specific study. Duchowski (2007) divide the different systems into 4 generations, which will be briefly touched upon here (Duchowski (2007) pp. 49-59). The first generation consists of "schleral contact lenses" or "search coils", in which the participant has a contact lens inserted into the eye, with either small mirrors or a coil of wire attached to it. In the case of the wire-solution the movement of the eyes, or the wire, is monitored through a magnetic field (Duchowski (2007) pp. 49-59). While direct physical contact with the eye provides very sensitive and precise data, the contact lenses are enlarged to avoid slipping and instability and is provided with attachments, and having them inserted into a participants eyes takes practice and care and is quite invasive (ibid.). Another method from the this generation is the "Electro-oculography" or "EOG". In short the EOG monitors the skins electrical potential differences, using electrodes placed around the eye. The methods were very popular 40 years ago, and tracks eye-movement relative to head-position, but the head-movement needs to be tracked separately if it is to measured where the eye is looking (ibid.).

The second generation includes "photo-oculography" and "video-oculography". Both involve shining a light-source, often infrared, into the pupils of the participant, from a closely situated source (Duchowski (2007) pp. 49-59). The movements and shape of the pupil and the limbus and the corneal reflections are then taped and with some systems the measurements and calculations of the eye-movements are tracked automatically, while in other systems it has to be done manually, by e.g. measuring a video frame-by-frame, which is a time consuming process (ibid.). These methods do not generally provide a point-of-regard measurement, but are good for tracking eye movements (ibid.).

The third and fourth generations of eye-tracking methods are video-based, the third being analog and the fourth being digital, but both use either corneal reflections or a combination of pupil and corneal reflection (Duchowski (2007) pp. 49-59). While the methods of the first and second generations generally are incapable of providing point-of-regard measurements without the head movements also being tracked, or the head being fixed, the methods using corneal/pupil reflections are. In these methods several points of light (again often infrared, because it is invisible to the human eye, and makes it less intrusive) is shone onto the cornea, and the movement of the cornea is then compared to the movement of the pupil (see fig. 9) (ibid.). Using these two reference points for tracking eye-movement it is possible to measure pure eye-movement since, the position of the cornea and the pupil changes with eye-movement, but are relatively unaffected by head-movement (ibid.).

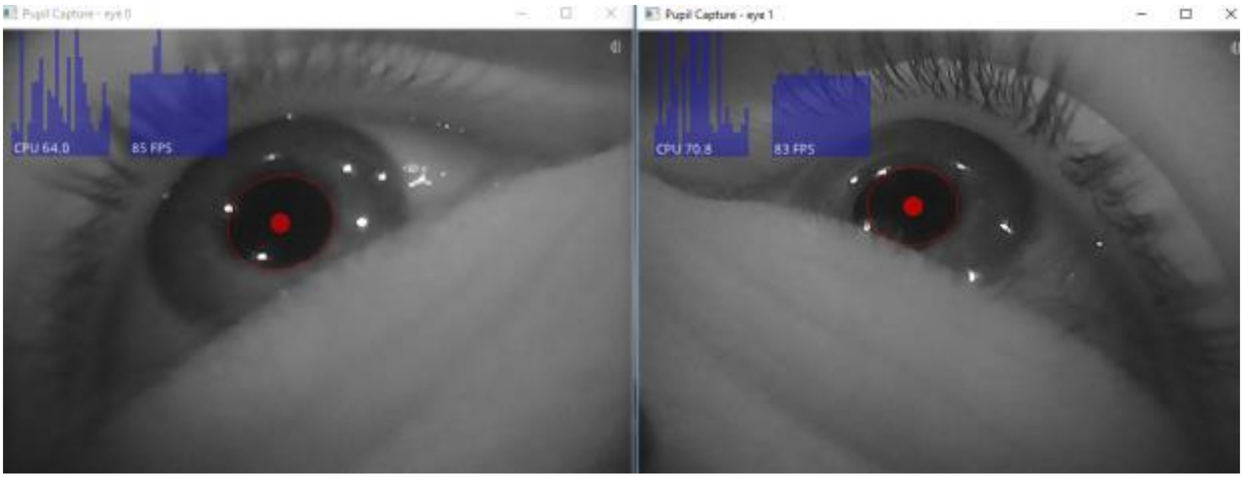

Fig. 9 reprinted from 9th semester project

Using digital video-based combined pupil/corneal reflection, it is possible to make accurate measurements of eye-movement and point of regard using saccades and fixation points. With the ongoing development of stronger and faster processors for computers it is possible to collect larger and larger amounts of data in a smaller timeframe, which allows for a relatively precise measurement of what participants are looking at, how often and how long. The ability to compensate for small head-movements have made these methods the most popular eye-trackers at the moment (Conklin et al. 2018) pp. 15-33). The cameras used to capture the rotation of the eye can be relatively cheap and several different systems have been developed to track eye-movement this way. Conkling et al. 2018 separate these methods into three categories:

1. "High-precision head-stabilised" eye-trackers, which monitors the eye movement from a constant distance and steady illumination, with a zoomed-in-view of the eyes. The camera

and infrared light can be placed at a distance from the participant, such as on a desk in front of a computer monitor, or in a tower option where the participant has a headrest, which fixates the head to some extent, and with the light and camera very close to the eyes. While being very precise it does not allow for a lot of movement or head-orientation, which would be expected when fairing in a natural setting e.g. traffic (Conklin et al. 2018) pp. 15-33).

2. "Remote, head-free-to-move" eye-trackers are also desk-based with a zoomed-out, low magnification view of the eyes, but allow for head-movement to some degree. Since the illumination constantly changes with head-movement, the data-quality may impacted. These eye-trackers allow for a more natural feel due to the increased capacity for head-movement, which supports ecological validity to some extent (Conklin et al. 2018) pp. 15-33).
3. "Head-mounted eye-trackers". As the name implies, these trackers are mounted to the head of the participant. These trackers can be a large mount such as a cap or a helmet, which include a head-tracker, which monitors head-movement in relation to the scenery a participant is looking at. The large mounts can provide good accuracy and are less affected by head-movement, but are fairly heavy, which can make time consuming experiments unpleasant. A different type of head-mounted eye-tracker are the eye-tracking glasses. The glasses are light-weight, with cameras and infrared light imbedded into the glass frame. The participant can wear the glasses and they can be used remotely from the computer, which processes the sample-data. This ensures great mobility and the participant can wear them in more natural settings, which secures high ecological validity. However, they have a tendency to provide less accuracy and when using the glasses there is no or less control of what the participant is looking at (Conklin et al. 2018) pp. 15-33).

8.2 Validity of eye-tracking

Eye-tracking has been used in several studies on spatial cognition, including studies on spatial neglect. One such study was made by Kortman and Nicholls (2016). In their study, they argue that the traditional standardised pen-and-paper-tests lack ecological validity are inconsistent as an assessment tool for identifying neglect, are ineffective in providing adequate and reliable information about how badly the patient is impaired, and that they have a tendency to miss the patients with mild cases of neglect (Kortman and Nicholls (2016) pp 345-347). They argue that the standardised tests are incapable of capturing the complexity of the spatial neglect syndrome. Many patients do not have spatial neglect, according to the tests, but still have issues in their everyday life and the tasks such as driving, which is a complex task, that require the ability to be responsive and attentive to the world around you (ibid.). While doing fine on the pen-and-paper-tests, the patients may have difficulties doing dual-tasks (ibid.).

While there are screening methods, that provide validity and sensitivity to spatial neglect, such as The Catherine Bergego Scale, it demands following the patients around in the daily activities and is very time consuming. They argue that it doesn't really matter which type of assessment is being used, none of them explores how the patient scans and explores the neglected side (Kortman and Nicholls (2016) pp. 345-347). They did a study using eye-tracking in order to see what the gaze patterns of neglect patients looked like, when they were performing a task. For equipment they used Tobii glasses, which is a light-weight head mounted eye-tracker resembling a pair of glasses (ibid.). They had 13 stroke patients participating in the study, seven with confirmed spatial neglect (right-sided) and six patients who did not suffer from spatial neglect. They had to leave out one from the spatial neglect group, because they could not get the glasses to calibrate properly and one from the non-spatial neglect group, because the patient became too agitated to finish the tasks (ibid.).

The patients were taken to a kitchen area at the rehabilitation program, and asked to make a cup of coffee (Kortman and Nicholls (2016) pp. 347-355). The kitchen was split into 3 areas, in which the patient had a task in each. In the refrigerator, the participants were asked to find a carton of milk, in the cupboard they were asked to find the coffee, and in the kitchen drawer they were asked to find a teaspoon (ibid.). They tracked the gaze-patterns of the participants. They found that there was no significant difference between the time the non-spatial neglect group and the spatial neglect group spent searching for items on the left side (ibid.). But there was a significant difference between the two groups when searching for items on the right side of the drawer and the refrigerator, and nearly a significant difference between the groups when searching the right side of cupboard (ibid.). All in all the patients from the spatial neglect group spent 30 seconds on average more than the other group when doing the kitchen task (ibid.). The sample group is rather small, but the study does pose some interesting findings, which could inspire to further research.

8.3 Summary

Eye-tracking is an interesting research tool, that comes in many different forms. Duchowski and Conklin et al. presents the different versions of eye-tracker systems from the stationary table based types and the heavy and fast tower types to the mobile modern eye-tracking systems. We go through the investigations made by Kortman and Nichols where they argue that the old pen-and-paper-tests lack ecological validity. They try to solve this by using Tobii glasses and introducing their patients to a familiar scenario where they have to make a cup of coffee. By tracking them with the Tobii glasses they have the opportunity to clearly follow how the participants do in their task. How long it takes them to find the items they need to make the cup of coffee, gave some interesting results, which may support the idea that eye-tracking is a viable way of improving on the traditional pen-and-paper tests for assessment of spatial neglect.

9.0 VR

A way of using eye-tracking to assess and rehabilitate visuo-spatial cognition could be through the combination with Virtual Reality. Virtual reality has undergone a lot of development over recent years, primarily for use in the gaming-industry. The virtual world is becoming more and more complex with newer systems such as the “Oculus rift” or the “HTC Vive”, which allow for a high-resolution, immersive virtual reality space, which is increasingly resembling the real world.

Before the upsides and downsides with using virtual reality can be discussed, it is important to establish what applications virtual reality can have in neuropsychological research, and more important, what virtual reality is, since different sources have different ideas of what virtual reality can be. Buxbaum et al. (2012), created a system called the VRLAT, which was meant to compete with the traditional pen-and-paper-tests used for assessment of neglect patients (Buxbaum et al. (2012) pp. 430-440). While they concluded that the test could outperform the traditional pen-and-paper-tests in terms of specificity and sensitivity, they system was built around a 15.5 by 17.5-inch flat screen TV. The participants were equipped with a joystick and were to use it to navigate on a virtual path and avoid obstacles (ibid.). In some cases, the examiner would hold the joystick, and move it accordingly at the report of the patient (ibid.). In this project, the focus is on “immersive virtual reality”, which offers a wide field of view and the ability for the participant to investigate their surroundings 360 degrees around them, using a head-mount.

Studies have been done using a virtual reality head-mount, where the patients with spatial neglect have had the ability to investigate the virtual environment 360 degrees around them. One such study was done by Aravind and Lamontagne (2015). They used an nVisor SX60, which in capability resembles that of the newer HTC Vive head-mount, but it weighs twice as much Aravind and Lamontagne (2015) p. 179-188). Aravind and Lamontagne (2015) attempted to create system with high ecological validity by having the patient immerse themselves in a virtual room, which in dimensions resembled the real-world room the patient was in (Aravind and Lamontagne (2015) pp. 179-188). In the virtual environment the patient was asked to perform two tasks in the virtual reality room. In the far end of the room was a blue target, which the patients were asked to reach, walking at a comfortable speed (some of them used canes), in the first task. 3 red cylinders represented obstacles and the participants were asked to avoid these, but now how to avoid them (ibid.). When a participant collided with one of the obstacles, they received visible feedback in the shape of a flashing sign in front of them. In the second task, the participants were seated with a joystick in the hand ipsilateral to their lesion, on which they were asked to press a button when they perceived a moving obstacle (ibid.). They found that patients with spatial neglect exhibited a delayed perception when trying to avoid obstacles on the contralateral side of their lesion, but also moving obstacles moving right in front of them (ibid.).

Virtual reality provides an opportunity for neuropsychological researchers to create an increasingly lifelike scenario in which the participant can solve tasks and be monitored in a safe and controlled environment, where variables such as lighting can be manipulated at will. It allows for researchers to create scenarios and tasks, that somewhat resembles everyday life and gives a more life-like feel than a virtual experience on a computer monitor or on a screen on other devices. This is caused by the ability to more directly interact with the world around the participant e.g. by the world represented in the field of view changing corresponding with the movement of the head.

10.0 ET/VR pros and cons?

10.1 Pros/cons of ET

Eye-tracking provides researchers with the opportunity to track the gaze patterns of the patients participating in their studies. The technology has become cheaper and more available in the recent years. It has also become far more mobile over the years, which gives researchers the opportunity to let their participants move freely about with equipment such as the light-weight wearable Tobii glasses mentioned in 8.2. Eye-tracking can provide us with unique insights on how attention works and how the participants visually experience the world around them. Where the pen-and-paper-tests have been criticised for lacking ecological validity, using wearable eye-tracking systems provide the opportunity for researchers to directly track what the participants are looking at in the natural environment of their everyday activities. Systems such as the Tobii glasses are close to non-invasive since the infrared light used in systems with digital video-based combined pupil/corneal reflection, is not visible to the participant. While eye-trackers can offer us a unique and detailed view of how humans scan their surroundings, there are a few issues with using them. The most accurate eye-trackers are quite heavy stationary equipment, which does not allow for great mobility, and several of them are vulnerable to head movements. A larger head mount is a little heavy but counteracts the head movements, and the glasses-like wearable eye-trackers give great mobility, but are less precise. They do not offer any statistical results that can tell us about tactile experiences or locomotion, but give a good insight into the visual experience.

10.2 Pros/cons of VR

Virtual reality provides researchers with the opportunity to let their participants immerse themselves into a virtual environment. The virtual environment is programmable and flexible, which allows researchers to create different tasks for the participant to solve and scenarios for them to explore. The environment it creates can help simulate real-life situations and give researchers the ability to observe human behaviour in a safe environment. For studies in spatial neglect, VR can provide a test environment, which could increase the ecological validity the pen-and-paper-tests lack. The issues with using VR is primarily that it is difficult, but not impossible to create a sense of locomotion and proprioception. Unless VR gloves or other types of sensors, which captures the body's movements and indicate them in the virtual environment, are used, accurate proprioception could be a major issue.

10.3 Combining the ET/VR

Eye-tracking and virtual reality offers a series of new and interesting opportunities for neuropsychological research (Kiefer et al. (2017)). The combination of the methods are, perhaps, particularly useful when researching attention disorders and spatial cognition in general, since the eye-trackers can provide live data on where the participant looks and what they fixate upon, and a virtual reality head mount could provide a safe and pliable environment for testing to be done. Immersive virtual reality head mounts monitor head movements in order for the virtual environments to follow the user's movements. Right now the primary way of detecting and measuring spatial neglect has been traditional pen-and-paper-tests. The key issue with the traditional pen-and-paper tests is the lack of ecological validity. Cancellation-tasks, drawing tasks, organisational tasks, physical movement tasks, can indicate spatial inattention, but says very little about how the patient fares in their everyday life, or how they e.g. react to incoming objects or distractors in traffic. A different, but perhaps quite significant, issue with the traditional tests, is the lack of precision with which data can be obtained. A drawing or a cancellation task, can give a clear indication of abnormal spatial attention, but are more difficult to quantify than eye-tracking data. Moreover, with the amount of raw data, a powerful processor can obtain, could potentially show patterns, which indicate spatial neglect in a degree too subtle to show up in the traditional tests. Another issue is how time consuming these tests can be, which can be a strain on both the patient and the therapist administering the tests.

10.4 Summary

There are many advantages to using ET and VR as tools to improve on the traditional pen-and-paper methods. The tools can provide a safe environment within a laboratory setting, in which different tasks can be implemented. The environment could have more ecological validity and combining virtual reality with eye-tracking could produce some more sensitive results. Now that that has been established it is possible to move on the one of the main questions of this thesis. Would the use of eye-tracking and virtual reality actually be an improvement?

11.0 Improvement?

11.1 Assessment

The combination of eye-tracking and virtual reality may improve on different methods of assessment such as the cancellation-tasks (see 5.3). It would be possible to create a virtual environment in which the patients could be asked to search for targets. Eye-tracking could give a clear image of which targets the participant is fixating on, which could be basis for assessment of spatial neglect. Aravind and Lemontagne (2015) had a solution in which they had neglect patients try to avoid dynamic obstacles, which could be a possibility mode of assessment. One of the criticisms om the wearable eye-trackers is that it is difficult to control where the participant is looking. However, in an assessment study, where the intention is to find out where the participant does not pay attention, this is not necessarily an issue (see 8.1). Another test of spatial cognition, where the combination of VR and ET could be an improvement, could be in the UFOV. The UFOV uses a computer monitor to test the participants useful field of view (see 7.0). Creating a simulation in a virtual environment, would offer an opportunity to have a more dynamic environment and further improve on the lack of ecological validity, that the UFOV was originally created to rectify. The simulation could contain moving obstacles, changing traffic lights, and sudden changes in lighting and in the environment, and it would be possible to track reaction times with eye-tracking. This way it is also possible to create a test, that could resolve some of the issues the pen-and-paper-tests have with environmental scaling (see 3.2). It would also be possible to create a task such as the double simultaneous stimulation task. All of the tests would have quantifiable eye-tracking data and can be filmed for further assessment. However, with tasks such as the baking-tray task, the copying task or the clock drawing task, where a sense of proprioception is necessary, the ET/VR combination may not be an improvement. The question is how much of our spatial cognition is actually visual? Granted a lot of it is visually dependant, such as route planning and navigation from an online-processes point of view, since vision is the sense that allow us to see far and as a sense it reaches much further than our sense of smell, tactile or proprioceptive senses.

11.2 Rehabilitation

The ET/VR combination could prove useful with some of the rehabilitation methods available at the moment. Methods such as OKS, VST and prism adaptation could easily be integrated in a virtual environment (see 6.1, 6.2 and 6.5). With the VST a natural environment such as a living room could be created and then have the patient locate specific items in the room. With the OKS a virtual environment could be created where the entire field of view moves to one side. With prism adaptation, a similar scenario could be implemented, where the entire environment Is slightly skewed to one side. By using VR gloves, it is possible to have the participant point at target and be able to see where they are pointing. A working system could be combining several approaches, such as the VST and the NMV (see 6.3), or the VST and CVs and GVS, so there is a tactile element present. The combination of ET/VR could be used to create a more natural-feeling environment, and might be able to tell us more about the participants' abilities and problems in their everyday life, and could, thanks to eye-tracking, perhaps create a more sensitive system, that has the ability to assess and rehabilitate patients with very subtle spatial neglect.

11.3 summary

There are several ways in which eye-tracking and virtual reality could be used to directly improve on the pen-and-paper-test for assessment by implementing them into the virtual reality system. Rehabilitation methods such as the VST and OKS may also be implemented into the virtual reality system and may be combined with NMV.

12.0 Conclusion

In conclusion, eye-tracking in immersive virtual reality, could possibly be used to improve the assessment and rehabilitation of visuospatial cognition. By presenting what spatial cognition is, and what issues there are with the traditional pen-and-paper-tests in terms of assessing spatial cognition, an opening to a discussion about the serious issues with ecological validity and scaling that the tests have. According to Montello (1993) the primary issue with the old pen-and-paper tests is their inability to use other scales than the smallest pictoral scale to assess spatial cognition, and instead tries to conclude something about the real world issues a spatial neglect patient experience on the basis of something that says so little about larger spaces, distractors, collisions with objects and the general ability to navigate in an environment. A common way of assessing spatial cognition is to examine and test patients, who suffer from spatial inattention. One of the more common forms of spatial inattention is spatial neglect. Spatial neglect is a common consequence of hemi-parietal stroke and understanding the processes and mechanisms of stroke could be useful in understanding the neglect syndrome. After presenting the common practices for spatial neglect assessment it is possible to get different perspectives on what the issues with these methods are. Likewise, it is important to understand what the common methods of rehabilitation of spatial neglect are, and what issues there are with these. The primary issues seem to be a lack of ecological validity since the pen-and-paper assessment tests say very little about what problems a spatial neglect patient faces in real life, and they seem to be too insensitive to assess spatial neglect when it is mild and subtle. The UFOV was created in order to assess the driving capabilities of elderly vehicle drivers, and it was meant to resolve some of the ecological validity issues with the old assessment methods, but it in itself is confined to a computer screen which can also be criticized for lacking ecological validity. Implementing a ET/VR combination could help absolve some of the problems with ecological validity, such as more lifelike visual experiences, and more sensitive tracking and gathering of data, but it might not be able to solve all of the problems. Proprioception and locomotion is difficult, but not impossible to create in a virtual reality space. If a system is created that incorporates those sensations, eye-tracking data, an ecological valid environment, and a set of tasks, which incorporates tactile stimulation such as the NMV, then ET/VR could be an improvement to the existing methods of assessment and rehabilitation of visuospatial cognition.

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