From vision science to design practice

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1. INTRODUCTION

The aging process is characterized by progressive and multiple acquisitions of some deficiencies, predominantly related to vision, hearing, dexterity, mobility and cognition, which can lead to high levels of disability and dependency. This process includes physical degeneration, with reduction of the overall physical condition, reduction of agility, impaired vision and loss of hearing, memory faculties, and sense of direction. Deficits lead to changes in sensory perception and decreased sense of well-being, which often involves strong feelings of insecurity (Meerwein, Rodeck & Mahnke, 2007). Knowledge about vision, color vision, perception, color interaction, chromatic contrasts, should always be present on the design process. The same way, Inclusive Design should help people and communities to prepare themselves for future, as well as should improve quality of life in the present. Designers and architects need to create environments that are easier on everyone’s eyes with or without visual impairments. Visual design objects and environments should be completely used by older people, should be easier to read, and should consider to meet the visual needs of this growing population.

Although the anatomic and physiologic processes of aging are distinct from the aging eye diseases, the vision changes they produce may be similar. Knowledge about these problems is essential to understand the mechanisms underlying age-related changes in visual function.

Information about neuro anatomical changes in the visual system helps guide the development of strategies for compensating age-related deficits in visually-guided skills (Schieber, 1994).

With the aging process, the gradual decline in the functioning of vision will affect performance of most daily visual
tasks. Color contrasts and color combinations, with proper lighting, can make all the difference in the case of people whose vision is impaired as a result of aging, reducing risks and increasing safety. The challenge will be to create objects and environments that can help compensate for the most common types of vision loss, improving the remaining vision with lighting and proper use of contrasts and colors. Design that is more visually accessible - and not just visually appealing - can change lives for the better (Evamy and Roberts, p.5).

2. THE VISION MECHANISM

The mechanism of vision and color vision involves a complex system composed by the eyes and the brain. Vision is perhaps the most important human sense, and also the most complex from physiological point of view, and there is still a lot to discover. Although color vision is a widely studied subject, there are still aspects from processing visual information in the brain which remains partially unknown. Perception is a sensation perceived by the individual through the senses and combined with an interpretation performed in the brain.

The retinal cells, when excited by light rays generate electrical impulses that are conducted through the optic nerve to the brain. When the electrical impulses reach the visual cortex they are decoded and recombined to create the image. The retinal receptors (nerve cells specialized to transform optical signals into electrical signals), when excited by the light rays, generate electrical impulses that are carried through the optic nerve to the brain to be interpreted. The brain gives meaning to these signals, extracting useful information from a biological point of view and turning it into conscious information. "The building of the external world in our minds requires the detection of physical energy from the environment and codification in neuronal signals, as well as the selection, organization and interpretation of our feelings. The first one is a process traditionally named as sensation and the second, a process traditionally named perception" (Durão, 2006).

2.1 Distinction between low vision and blindness

The term "visual impairment" can be used for all situations, from low vision (partial impairment) to blindness (total impairment), but indicates that the classification is based on a measurement of the visual function (visual acuity, visual field, etc.), rather than an assessment of functional vision, for example, the ability to read newspapers. There is no universal consensus on low vision and blindness definitions. In a broader sense, low vision can be
defined as any visual impairment that can't be corrected medically, surgically or with conventional glasses (The Eye Digest, April 26, 2007). Someone with low vision has a severe reduction of visual acuity or contrast sensibility, a significantly blocked field of vision or all three conditions.

"Normal sight is "the ability to see comfortably what is around us, whether far away or near, with or without glasses" (Canadian Ophthalmological Society, apud Evamy and Roberts, 2004, p. 37). This normal vision is often referred to as 20/20 vision. This means that a person can see clearly at 20 feet what should normally be seen at that distance.

The vision between 20/60 and 20/190 is described as low vision, and means that a person can see at 20 feet what could be seen for a person with normal vision at 60 to 190 feet. This is already considered partial sight.

People are classified as blind, despite they may be able to see something, when vision is at 20/200 (Evamy & Roberts, 2004). If a person sees 20/200, the smallest letter which can be read at 20 feet, could be seen by a normal eye at a distance of 200 feet. This is the Snellen acuity test (Watt, 2003). Fractions, 20/20, 20/30, etc. are measures of vision sharpness, related to the ability to identify small prints, with high contrast, at a specified distance.

Blindness is a condition with loss of abilities to perform all visual tasks such as reading, face recognition, cooking etc.

August Colenbrander, from Smith-Kettlewell Eye Research Institute and California Pacific Medical Center, explains that contrary to what is commonly thought, 20/20 is not actually normal vision or the average, much less the perfect acuity. Snellen set a standard reference. The normal visual acuity in healthy adults is one or two better rows. The average acuity in a sample of population does not fall to the level of 20/20 until the age of 60 or 70 years. This explains the presence of two smaller lines down 20/20 - 20/15 and 20/10 (Strouse, 2002).

**Amblyopia**, also known as low-vision means a reduced visual capacity - whatever the origin - that does not improve using optical correction. There is a low visual acuity either of organic origin, (organic amblyopia - with injuries to the eyeball or the optic tracts), whether functional (functional amblyopia - without organic damage).

Between 1/10 vision and total blindness there is a continuous line, where we can distinguish:

**a)** Light Perception - distinction between light and dark; **b)** Luminous Projection - distinction of light and the place from which it emanates; **c)** Shape Perception - vision of fingers up to one meter; **d)** Perception of forms and colors - vision of fingers at 2,5 meters.
2.2 Low Vision Symptoms

- Difficulties for recognizing faces from family or friends.
- Difficulties in reading - printed material looks distorted or incomplete.
- Difficulties to see objects and potential hazards such as stairs, walkways, walls, rough surfaces and furniture.
- Difficulties to perform tasks requiring good near vision, such as reading, cooking, sewing, fixing things.
- Difficulties to choose and match colors of clothing.
- Difficulties to perform tasks because light levels appear to be weaker than they used to be.
- Difficulties to read traffic signs, public transports, shop names, or other information in urban environment like signage.

Some of the most common causes of low vision are: Cataracts, macular degeneration (AMD), diabetic retinopathy, glaucoma, hemianopia, retinitis pigmentosa, resulting among others, in problems or discomfort with glare and bright lights.

Functional evaluation of vision is an important step to help improve quality of life. Vision is one of the primary senses and serious or complete loss of sight also has a major impact on a person’s ability to communicate effectively and function independently.

3. COLOR VISION AND COLOR PERCEPTION

Color vision involves a complex mechanism composed by eyes and brain. The capacity to distinguish different colors is due to physiological process that occurs in the eyes, when the light reaches the retina, but it’s subordinated to a whole of neural processes in the cortex. A substantial quantity of visual information treatment occurs in the eye, but the fact is that an even bigger quantity occurs after the nervous signals have left the eye. It is in the brain that the visual stimuli are elaborated and associated in underlying structures to the basic mental functioning. Although much information about the external reality comes from the sense of vision, the answer to its profitability is in the brain. “The phenomenon of color vision includes the ability not only to discriminate between different colors, but to respond to them as a means of conveying information, stimulating emotions and practising deception” (Lancaster 1996, p.112).
So color is a sensory perception, a specific visual sensation produced by visible radiation that is interpreted by the brain. "Color is not the property of objects, spaces, or surfaces, it is the sensation caused by certain qualities of light that the eye recognizes and the brain interprets" (Mahnke, 1996, p.2).

When light rays pass through the eye, several structures help to refract the light to focus appropriately. The first of these structures is the cornea and next is the aqueous humor in the chamber behind the cornea which helps to feed it and maintain its curvature.

The light continues the way, passing through the pupil (whose size is adjusted by the iris) that controls the amount of light. Then, the light rays reach the lens, a transparent disk suspended in muscles that change his form. This adjustment process known as accommodation, helps to project light correctly on the retina, improving the visual acuity. After passing through the lens, the light moves through a large chamber filled with a clear and viscous substance called vitreous body.

The retina is composed from three cell layers, one of which containing the receptors, rods and cones. *Cones* - are receptors sensitive to color, located preferably in the fovea, and are responsible for color vision; Are of three types - *Cones S, M and L*, depending on their sensitivity: S cones, are sensitive to blue - receptors sensitive to light of short wavelength; M cones are sensitive to green- receptors sensitive to light of medium wavelength; L cones are sensitive to red - receptors sensitive to light of long wavelength.

*Rods* are colorblind and converge on the retina's bipolar cells. As a result, they have poor acuity but they support our perception in low lighting levels (*scotopic vision*). Cones, sensitive to color information, are responsible for acuity and vision in daylight conditions (*photopic vision*). The posterior pole of the retina is constituted by *macula lutea*, region of the retina responsible for central vision, where are located most of the cones.

The retina is the inner layer of the eye, and the endpoint of the light movement through the eye. The *blind spot* is the point on the retina where the optic nerve fibers are joined and blood vessels enter/exit the eye and does not contain cones or rods.

The brain performs the task of cortical color processing in a very complex way. The elementary units of the brain are the neurons. The neural system underlying the vision begins in the retinas, but the region responsible for vision lies in the visual cortex in the occipital region of the brain.

The images are organised in such a way that information which either one or both eyes see in the left field of vision travels to the left half of the brain, and information which either eye sees in the right field of vision travels to the
right side of the brain.

Insert figure 3.1

Figure 1: Binocular vision and optic tracts. (Modified from Fehrman, 2004)

The brain is divided in two halves and form two complexes hemispheres, that are connected by the corpus callosum and the optic chiasm, the region where the optic tracts cross to the opposite hemisphere; Before reaching the cortex, the retinal potential actions are diverted through an area of the brain called the lateral geniculate nucleus (NGL), which transmits a huge amount of visual information to the primary visual cortex.

At the optic chiasm half of the axons of ganglion cells remain on this side, while the other half crosses to the opposite hemisphere of the brain and reaches two groups of cells - the lateral geniculate nucleus (NGL) located deep in the brain. The NGL send their fibers to the striate cortex. After synapsing at the LGN, the visual tract continues on back to the primary visual cortex (V1) located at the back of the brain within the occipital lobe. Within V1 there is a distinct band (striation). This is also referred to as "striate cortex", with other cortical visual regions referred to collectively as "extra striate cortex". It is at this stage that color processing becomes much more complicated.

All the process of transmission, decoding and interpretation of information occurs in an almost instantaneous time period. Some ganglion cells are particularly sensitive to movement and contrast, while others are more sensitive to form and details, and others transmit information about color.

In the area of visual cortex, the brain reconstructs the electrical impulses transforming into images, performing continuously every day without failure; however many aspects of this operation and capabilities still remain unknown. The conscious visual perception depends on this area of the brain called the primary visual cortex, also known as V1 area, area 17 of Brodmann or striate cortex. Other visual areas are continuously being discovered.

The area called 17 not only performs one visual task, but several: the blobs in the visual cortex, rich in cytochrome oxidase are specialized in receiving information about color, while interblobs areas separate at least two streams of information, describing movement, shape and depth (Zeman, 2007). The V4 area is essential to see colors and the V5 to perceive movement.

Neuroscience is continuously discovering correlations between the visual experience and the cortical activity. Zeki (2006) considers the visual brain not as an organ that passively narrates external events of our world, but is actively involved in producing what we see. Brain can "read" the activation of the three types of cones to create the
perception of multiple colors. Color vision has low resolution, while high resolution depends on the brightness differences.

Perception of color is an overall perception of all wavelengths of light that compose the visual scene. Color is examined in V4, dynamic form in V3 and movement in the cortex MT. The areas beyond V1 and V2 are more specialized to process the different attributes of visual scenes, such as color, shape or movement (Zeki, 1978; De Yoe & Van Essen, 1985; Shipp & Zeki, 1985; Livingstone & Hubel, 1988; Bartels and Zeki, 1998).

In addition to V1, there are two general streams processing information, one for movement and location and the other for color and form, which are known as the *ventral and dorsal streams* respectively. The ventral stream ends in the temporal lobe, the dorsal stream in the parietal lobe. It is the ventral stream that is more involved in the perception of color and form (Wagner & Kline, 2000).

The global color analysis appears to occur in cortical area V4. Unlike the cells in V1 and V2, V4 cells respond only to a narrow band of wavelengths. In V4 there is a direct correlation between the perceived color and the wavelength, made possible by a global analysis of information from neighboring cells. Damages in V4 can harm and even eliminate the ability to see or imagine color. Clinical evidence shows that damage restricted to a processing system, lead to a no perception (agnosia) of the attribute to which this system is specialized, but do not lead to a global blindness.

About the color processing system, we know that some individuals with lesions in V4 area (Bartels & Zeki, 1998), become with *achromatopsia* and only are able to see the world in shades of gray. They may, however, distinguish between different wavelengths of light, albeit with higher thresholds, but are unable to give them color names (Vaina 1994; W. Fries and Zeki, unpublished results, apud Bartels and Zeki, 1998).

### 4. DEFECTIVE COLOR VISION

Normal Trichromat is the individual who has a normal perception of all colors. Color vision considered normal is trichromatic, but there may be deficiencies in eye level and at the level of sensitivity to colors. People with proper functioning of all cones and a normal color vision are able to see all the mixtures and subtle differences between colors, using cones (retinal receptors) sensitive to the three wavelengths of light - red, green and blue.

*Discromatopsia* or Colorblindness is an inherited disorder in color vision and is linked with X chromosome, but the woman transmitting this color vision anomaly may be color blind or not. The different anomalous conditions are
protanomaly, which is a reduced sensitivity to red light, deuteranomaly which is a reduced sensitivity to green light and the most common form of color blindness and tritanomaly which is a reduced sensitivity to blue light and is extremely rare.

Trichromat- sees using all three colors receptors (red/green/blue); Anomalous trichromat- reception of one pigment misaligned (anomalous).

Dichromat- only 2 of the 3 visual pigments exist - red, green or blue is missing. Protanopia - abnormal red cones. Deuteranopia - abnormal green cones. Tritanopia - abnormal blue cones. Monochromatism - abnormal cones.

Protanopia affects one in every hundred men, two cones in operation, the absence of the L cone, without distinguishing between red and green. There are also less sensitive to light in the spectrum above orange. The brightness of the red, orange and yellow is much reduced compared to normal. Protanopes are more likely to confuse: Black with many shades of red, Dark brown with dark green, dark orange and dark red; Some blues with some reds, purples and dark pinks; Mid-greens with some oranges.

Deuteranopia affects one in a hundred men, 2 cones functioning, no cone M, without distinguishing between red and green. The deuteranope suffers from the same problems of color discrimination than protanope, but without the abnormal darkening, is unable to discriminate colors in the green-yellow-red segment of the spectrum. Deuteranopes are more likely to confuse: Mid-reds with mid-greens; Blue-greens with grey and mid-pinks; Bright greens with yellows; Pale pinks with light grey; Mid-reds with mid-brown; Light blues with lilac.

Tritanopia - 2 cones functioning, no cone S, without distinction between blue and yellow.

People affected by tritanopia are dichromats and only the sensitivity of cones to long and medium wavelengths are present, resulting in the inability to see colors in the blue-yellow range. The most common color confusions for tritanopes are light blues with greys, dark purples with black, mid-greens with blues and oranges with reds.

The monochromacy of L, M or S cones describes another condition where only one cone type works, and therefore, only a single color is perceived. People with monochromatic vision can see during the day but can’t distinguish between hues.

Achromatopsia is extremely rare occurring only in approximately 1 person in 33000 and its symptoms can make life very difficult. In Achromatopsia (sometimes called rod monochromacy), there is an absence of cones and poor visual acuity. Because an achromatic vision depends entirely on rods, they work better in low light levels, and peripheral vision. Usually someone with achoromatopsia will need to wear dark glasses inside in normal light
conditions. Achromatic congenital people perceive black, white and shades of gray, but do not understand the concept of color. People with cerebral achromatopsia see in shades of gray, but because they already had color vision, can perceive the absence of color.

5. AGED VISION

5.1 Elderly color perception

The aging process is unique to each person, and despite we are not able to accurately predict the specific effects of this process, most individuals will present changes in sensory organs as they age. It is through the senses that we establish communication links with the outside world. With the gradual reduction of these sensory abilities, communication can be modified, affecting the way the elderly receive and respond to all this information from the surrounding environment. (Larsen, Hazen and Martin, 1997).

Structural changes in the eye cause age-related functional disorders. But if vision is processed in the brain and brain functions also decrease, the processing of visual information as well as the interpretation capabilities are also processed more slowly. Within the aging process, visual functions gradually decline, changes occurs in the eye, retina and visual nervous system, and the quality of vision worsens; these changes in vision are normal but they are not diseases.

The most common problems of aged vision are: loss of focusing capability presbyopia, senile miosis, decreased visual field and depth perception; decreased visual acuity; loss of central vision; difficulties with light-dark adaptation; increased sensitivity to glare, dazzle with the brilliance; loss of contrast sensitivity, reduced ability to discriminate colors. Some of the most important changes in ageing eye include these anatomical changes:

- **Reduction of pupil size** - the maximum diameter begins decreasing and becomes smaller with the aging process (senile miosis). Under conditions of dim illumination, the resting diameter of the pupil falls from approximately 7 mm at age 20, to around 4 mm at age 80 (Lowenfeld 1979 apud Schieber, 1994). The area of the pupil controls the amount of light that can reach the retina. With age, also decreases the extent to which the pupil dilates, and because of the smaller pupil size, older eyes receive less light at the retina; Most of older adults spend more time adjusting to changes in levels of illumination, and have greater difficulty seeing in dim light. A 60 years old person receives only about 40% of the same amount of available light received by one of 20 years of age.
- **Loss of focusing capability** - Presbyopia, incapacity of see correctly near objects, can be corrected with eyeglasses. Is one of the most common degenerative changes associated with aging. It is not a disease, it is the natural evolution of vision, whose symptoms begin at 40-50 years of age.

- **Decreased visual field and depth perception.**

- **Difficulties with light-dark adaptation** - Most older adults take more time adjusting to changes in light levels and have more difficult to see in low light conditions. It has been estimated that for the same level of light, a retina of a 60 years person receives only one third of the light received at age 20 (Figueiro, 2001). Even if there is enough time for adjusting the eye to darkness, at 60 years of age we need ten times more light than at age 20, to detect the presence of light, and at age 80 we need 100 times more than at age 20 to detect that light. This demonstrates how strong age related deficits in light sensitivity are. However, in normal lighting conditions, at age 40 we need twice the light that is required at age 20, and three times more light at 60 years.

- **Increased sensitivity to glare, dazzle with the brilliance**; Glare also negatively affects the perception of contrast. Older adults feel visual discomfort under bright light conditions, or at night with oncoming headlights.

- **Loss of contrast sensitivity** - means the need of sharper contrasts and sharper edges to discriminate between objects; it is true that older people need contrasts 3 times and a half higher than individuals of 20-30 years. Owsley and colleagues (1983) determined functions of contrast sensitivity of 91 persons aged between 20 and 80 years. The results showed that from the age 40, the contrast sensitivity of higher spatial frequency starts to decrease, and at age of 80 is reduced to 83%. The function of contrast sensitivity for older observers is affected by low light conditions (Owsley et al, 1983 apud Connolly, 1998).

  This loss of contrast sensitivity means that strong contrasts and sharper contours are required to distinguish objects.

- **Decreased visual acuity; loss of central vision** - Loss of clarity in the visual field means that the affected individuals will see the world as a damaged image with unclear objects; as the viewing conditions get worse, the perceived images will become progressively more blurred and indistinct (Barker, Barrick, Wilson, 1995).

  Along with the gradual reduction of the amount of light that reaches an aged retina, also increase the opacity of the ocular media. The cornea remains clear but becomes thicker and more likely to scatter light. The lens becomes more dense, more yellow and less elastic.
With the increasing opacity of the lens, accommodation is reduced. Accommodation is defined as the ability to focus, ie the ability of the lens to change thickness and be able to focus at short distances.

Partial sight, ageing and congenital disabilities of color vision, produce changes in perception that reduce visual effectiveness of certain color combinations.

Shinomori (2005) states that although color appearance changes little with age, the ability to discriminate colors is significantly reduced in certain conditions. Because the yellowing of the lens causes a selective absorption of short wavelength light, the ability to discriminate colors is reduced mostly on blues and greens. Blue color may appear dark and hard to distinguish from green, because the lens absorbs blue light selectively.

The yellowing of the lens, the progressive opacity and loss of transparency are the most important causes of decreased visual performance of the aging eye. Consequently, the ability to distinguish some color contrasts decrease, and also decreases depth perception, affecting the perception of differences between figure and ground, the three-dimensionality; also perception of violet, blue and green becomes more difficult (Mahnke, 2006). Color blue may look dark and hard to distinguish from green because the elderly yellow lens absorbs selectively blue light; violet, blue and green are perceived as paler; therefore, when using these colors, is better to choose them in a more strong hue. The blue/green area of color spectrum becomes harder to distinguish than red/yellow end. Most older individuals have more difficulty seeing in low light conditions. It is believed (Fairchild, 2005) that yellowing of the lens is responsible for this effect. Aged lens causes glare by scattering light, absorbs and scatters shorter wavelength light (blue and violet). As it hardens, the level of this absorption and scattering increases. In other words the lens becomes more and more yellow with age.

With aging, other problems may interfere with vision and the ability to perceive colors by older adults: cataracts, ageing related macular degeneration, glaucoma, diabetic retinopathy and retinitis pigmentosa. As a consequence, color vision, night vision, visual quality and lighting entering the eye decrease in this group of people.

**Cataracts**- Are cloudy areas in the lens, causing decreased visual acuity, blurred vision, glare and reduced color perception, fragmented and unfocused vision. People with cataracts also have a decreased depth perception, making it difficult to discern whether the objects are placed in the background or foreground. ”The haze element of the crystalline lens greatly affects color perception of objects in the way that all the colors are desaturated. This point has been often neglected and only the color element was treated. We like to emphasize that more attention should be paid to the haze element when we investigate the color vision of elderly people” (Ikeda, 2009).
The perception of color improves after cataract surgery and most patients notice a greater brilliance in colors of blue area of the spectrum (Marmor, 2007).

According to statistics on elderly people, 70 percent of their eyes have cataract when they become ages between 65 and 69 years old, but the percentage increases to 100 at the age of 90 years old. This implies that to know about the vision of elderly people is to know about the vision of cataract eye (Ikeda, 2009).

After surgical removal of cataract, the stimulus of cone S greatly increases, usually resulting in a large change in color appearance. It takes about 3 months to stabilize the visual system, which exceeds the duration of other types of chromatic adaptation, according to a survey of the Department of Ophthalmology & Vision Science at the University of California Davis.

In a study of Obama et al in Panasonic, (Ikeda, 2009) it was found that after surgery, people stated that the fog disappeared, and they could see clearly people faces.

**AMD - Age related Macular Degeneration**- This condition also known as *Age-Related Maculopathy* (ARM), is associated with aging and gradually destroys the macula, a cluster of light-sensitive cells in the central part of the retina rich in cones, where the visual acuity and color vision are the best.

The macula includes the fovea, which allows a sharp central vision and allows to see the details. Central vision is needed to see objects clearly and for everyday tasks such as reading and driving. About 23 percent of people over the age of 65 show some form of macular degeneration.

People often report that the objects in their central field of vision becomes distorted, changing shape, size or color, and appear to move or even disappear. Visual acuity sometimes may fall to less than 20/400. The rest of the retina has no problem, so the peripheral vision remains normal.

**Glaucoma**- This is the name for a group of conditions where the optic nerve is damaged by the high pressure within the eyeball. It is often referred to as "the sneak thief of vision" because shows no symptoms.

Certain body tissues within the eye are fed by the liquid called the aqueous humor. The eye pressure is "normal" when the amount of produced fluid balances the amount drained. The eye needs a certain pressure to keep shape and size. However, with increasing fluid pressure, retinal nutrition is precluded, neural cells die, leading to the so-called "tunnel vision." It happens very slowly, on months and sometimes years.

If glaucoma is detected on time may be treated effectively; if not, the damage might progress, causing a loss of peripheral vision and may eventually lead to complete loss of vision.
As stated by Moreira da Silva (2011), Lakowski and Drance (1979) found that a large number of patients with ocular hypertension (OH) showed acquired colour vision losses. These losses were particularly in the blue-green part of the spectrum, the called tritan defects (Kelly, 1993). They seemed to precede nerve fibre bundle defects in the visual field (Drance et al, 1981, apud Moreira da Silva, 2011). This loss of chromatic sensitivity in the area of short waves of the spectrum in people with glaucoma was confirmed by others.

**Corneal edema** refers to a problem of the corneal tissue, which can cause scars on the inner layer A person with corneal edema is likely to see a color rainbow or halos around bright light sources, especially at night, when the brightness is more evident.

**Diabetic retinopathy**, one of the leading causes of blindness related to aging, involves dilatation of blood vessels and in a minority of cases the abnormal growth of new blood vessels (ie, neo vascularization).

These new vessels are fragile and might spill blood into the vitreous humor, reducing the light that reaches the retina and cause blurred vision They may also fail to provide the oxygen needed to meet the metabolic needs of the photoreceptors. The death of cones in this area can damage acuity and color vision. Diabetis can damage these blood vessels and can also cause cataracts and double vision.

**Optic neuritis** is an inflammation of the optic nerve which can result in blurred vision and distortion or lack of color vision. Although the cause of optic neuritis is unknown, it is believed that starts with plaque formation around the optic nerve myelin sheath. People suffering from optic neuritis reported increased sensitivity to light, eye movements pain, scotomas and loss of color vision.

**Consequences of visual aging problems:**

- Decreased visual field and visual acuity.
- Loss of central vision and contrast sensitivity.
- Reduced ability to discriminate colors particularly the blue and green area of color spectrum.
- Difficulties with light-dark adaptation.
- Increased sensitivity to glare.
- Dazzle with the brilliance.
- Decrease in contrast sensitivity and depth perception.
- Difficulties on reading and focusing near objects.
- Difficulty to perform visual tasks under dim lighting or changing levels of illumination.
Some research from Reading University has shown that although there is some knowledge in medical areas about how perception of color is affected by eye problems such as macular degeneration, cataracts, glaucoma, retinitis pigmentosa (affecting about 80% of the population in the United UK), very little of this knowledge has been associated with the decisions taken within the building and architecture (Bright, Cook and Harris, n.d.).

Findings from Project Rainbow from same University (1997), suggest that visually impaired people can determine color difference but there are areas where difficulties exist, mainly in differentiating blue toned green from green toned blue of similar lightness and chroma. Due to the declining vision following old age, very dark colors should not be placed next to each other since they seem to be difficult to distinguish, and the same goes for light colors.

Since color preferences remain more or less stable throughout life and since color and color design are highly appreciated among most people it is indicated that the color scheme ought to take a greater advantage of this than is common today Wijk (2012).

In the process of ageing the most disturbing aspect is the feeling that nothing happens without effort or at least as fast as before. The older see pieces almost as well as ever seen, but the organization of perception as a whole takes longer and requires more attention. Have to focus more, and perceive a complex situation is a slower and more difficult task.

6. INTO THE DESIGN PRACTICE

6.1 Light, Color and Contrasts

Light is essential for the perception of color. The visual senses of human beings work with three dimensions in order to perceive space. Light and color interaction is the base for the understanding space and the person’s innate or learned experiences are important when trying to interpret the surroundings and its spatial properties. Light and color are important parts within the physical environment and can be used to support this highly frail group of people, Nordin (2012).

“Understanding how the relationships between colors of a chosen palette will affect the final outcome of an overall composition is integral to mastering the use of color” (Moreira da Silva, 20011).

In optimal conditions of light, normal vision is good. Under dim lighting or with changing levels of illumination, some individuals have difficulty to perform visual tasks. Increasing ambient light levels to about 50% more than is
comfortable for a young, will increase vision. Aged and visually impaired people and others who are not recognized as visually impaired, may be unable to perceive some or all colors; however, they can perceive light and dark and since this is also a feature of colored surfaces their appearance can be influenced by the nature of the lighting condition, that can affect significantly the way color contrasts of an interior environment are perceived.

As stated before, partial sight, aging and congenital disabilities of color vision, produce changes in perception that reduce the visual effectiveness of certain color combinations.

Two colors, which contrast strongly for someone with normal vision, may be more difficult to distinguish for someone with a visual problem. Most of older individuals with loss of contrast sensitivity have more difficulty to see in dim light conditions, and they need sharper contrasts and sharper edges to discriminate between objects. It’s important to use color contrasts to increase visibility, and a conscious color scheme to make the environment attractive and safe for the elderly.

Wijk (2012), propose a more frequent use of contrasting colors in order to accomplish visual distinction in the environment, to support depth and spatial perception and to simplify object recognition. In addition, neutral colors and lack of contrast minimise attention contrary to strong color cues.

Different visual limitations mean different capabilities to distinguish color. Many people with decreased visual abilities are able to distinguish more readily between colors of different lightness than in the same color hue.

According to Mollerup (2005), when considering color differences, usually one thinks about hue differences: green, yellow, etc. However, for individuals with visual limitation, the brightness of a color is a more relevant parameter. To wayfinders with visual problems, it may be easier to distinguish between a light blue and a dark blue than distinguish between a blue and a red with the same brightness. The most important color contrast for visually impaired people is the contrast between color lightnesses, defined as color reflectance. To this people it’s more important and effective than contrasts of hue or contrasts of saturation.

Designers can help to compensate the deficits of elderly people by making colors differ more dramatically on the basis of all three characteristics - hue, lightness and saturation. “Two colors that contrast sharply to someone with normal vision may be far less distinguishable to someone with a visual disorder. It is important to appreciate that it is the contrast of colors one against another that makes them more or less discernible rather than the individual colors themselves” (Arditi, 1999).

Findings from researchers of Reading University suggest that visual disable people can determine color differences,
but there are areas where difficulties exist, mainly in differentiating blues from greens of similar lightness and chroma. We need to compensate for the most common types of vision loss, improving the remaining vision with proper use of contrasts and colors, balancing but improving the contrast between figure and ground, avoiding some opposite or complementary colors that are very difficult to read.

7. GRAPHIC DESIGN AND PRINTING GUIDELINES

Good legibility helps all users, but for people with low vision the issue is crucial for reading text.

Here are some guidelines for visual communication project and printed material:

• It is important to have enough contrast between the background and the text: the human eye requires contrasts for visibility and legibility.

• The more an object contrasts with its surrounds, the more visible it becomes.

• When color value is too close between text and background colors, it can create legibility problems.

• Too much contrast or the use of complementary colors takes the idea of contrast too far: colors will appear to vibrate and will create legibility problems.

• Colors that are close in value tend to blur together, and their borders melt.

• Black on red should be avoided when designing printed material.

• Black text on a dark blue background or black type on a red background are hard to read on a blue background yellow jumps out at the reader.

• White or yellow type on black or a dark color is more legible.

• Yellow text on a red background is difficult to read.

• Patterned backgrounds or an image in the background of text reduces its legibility.

• The most common forms of color blindness are associated with the inability to discriminate red and green wavelengths, so it is not effective to use red on green.

• Bright colors can produce glare, which might distract the user and cause the eyes to become tired.

• A clear open typeface (font) should be used for text.

• The characters must be of good proportions with clear character shapes. Avoid the use of too ornamented letters and with a complex design.

• Small type and very bold type tend to blur for some people, reducing legibility.
• Paper with a reflecting surface is not good for the legibility.
• Avoid shades of blue, green and violet for conveying information since they are problematic.
• Use no more than five colors when coding information.
• Be sure the elements have a contrasting color value unless you want the elements to just blur together.
• The use of too many colors might increase the chance of including a low contrast combination in the display.
• When using colors, one must have in mind that older individuals have a harder time distinguishing between colors in the cooler range - blues and greens particularly.
• Color is not appropriate as the sole differentiating feature between different elements - they should vary in other design features as well.
• Varying the value of colors (the lightness or darkness) by at least two levels, will enable most people to differentiate between the colors.

People with macular degeneration, the most common cause of decreased vision among older people, need more space between letters and between lines, to distinguish individual type characters and follow the shape of the text from one line to another. Many people with low vision also have difficulty with the glossy and very reflective papers that cause excessive glare.

Words or sentences which had no space between letters aren’t effective; and there are difficulties if there is no proper line spacing too. We should be careful choosing type fonts, because details may help to perceive differences and avoid confusion between type characters.

Insert Figure 3.2

Figure 2: Details that help to perceive differences and avoid confusion between characters. (Modified from Ralph Herrmann, 2011).

Among all the visual design elements, graphics and texts are inseparable from color performance. Aged people perceive less contrast between colors and perceived brightness is also different from people with normal vision. When selecting pairs of colors for typographic fonts and background, the contrasts of light against dark is preferable to emphasize the differences in hue or chromaticity.

In other words, the lettering is perceived faster and more legible when there are substantial differences in brightness between letter colors and background colors. Thus, colors should be manipulated to maximize contrasts and
facilitate perception. If we increase the contrast of brightness in a color design project, it will increase its visibility. Visocky O'Grady, (n.d.) recommends to accentuate the difference in 70% of brightness value between letter and background. Also Osborne (2001) refers to the same idea. The influence of contrast in reading is important not only because text of a wide range of contrasts is encountered in the environment but also because many ocular conditions lower the effective contrast of the reading stimulus. Most studies of the role of contrast in reading, however, have treated only the luminance dimension. In general, reading is found to be fastest when the luminance difference between text and background is maximal (Moreira da Silva, 2011).

In addition to biological changes, the differences in cognitive ability are also closely associated with aging. Heyl and Wahl (2003, apud Pettigrew, 2004) postulate that aging of the central nervous system, results in deterioration of the neural pathways to the brain, causing a slower cognitive processes including processing of visual stimuli. The ability of attention also decreases with age, meaning that cognitive processing becomes more demanding. It becomes more difficult to memorize new informations, especially if they conflict with other previously learned; nevertheless older people are able to conveniently process information if they are given enough time for that. Changes in visual acuity and cognitive processing related with age result in a need to modify presentation of texts, to maximize understanding by older people. The typographic characters should be slightly larger but not too large (Braus 1995, apud Pettigrew, 2004). We can’t separate the chromatic relations from other aspects that contribute to effective communication, such as typographic composition, formatting texts, shapes, proportions and scale of all elements that constitute the graphic design object. If one of the issues fails, the readability and the legibility get compromised. Printings in matte paper instead of glossy, presented in environments with minimal glare will improve readability and legibility (Braus 1995; Spotts and Schewe, 1989 apud Pettigrew, 2004).

8. INTERIORS AND EXTERIORS ENVIRONMENTS

Visually comfortable environments, where seeing well is easy and comfortable and is one effortless task, helps preserve sense of competence and independence of older people, improving their quality of life.

Good lighting can make the difference between seeing and not seeing for older adults with poor vision and between comfort and discomfort. Designers, caregivers, allied medical professionals, and other service providers can improve
quality and wellbeing of older people by recommending good lighting to mitigate some of the common problems associated with aging eyes (Figueiro, 2001).

- Light colors on the walls and ceilings reflect more light in an indoor space, which is often useful. Doors, floors and furniture should have darker tones to contrast with the walls.
- The use of plain colors and matte finishes help prevent dazzle, reflections and glare.
- Colors in contrasting shades are recommended to highlight furniture, equipment and potential dangerous objects and situations. A good color contrast can help locating emergency exits. Special attention should be given to location of mirrors to avoid confusion.

It is also suggested that color could be used to attract attention of cues in the environment of the elderly. For example it is well known that orientation in the urban environment can be facilitated by wayfinding cues, symbols and proper lighting to enhance visibility (Ulrich, 2006, apud Wijk, 2012).

In exterior environments, the characteristics of ambient light are much more difficult, if not impossible, to control; so hanging posters and outdoors in public spaces should safeguard the best visibility conditions, avoiding reflections or undesirable glare. In the case of advertising panels (mupis) with proper lighting, night visibility conditions are more guaranteed because the light box makes them stand out from the surrounding environment.

8.1 About lighting requirements

Generally speaking and also referring to interior spaces, lighting design should considers this aspects:

- Should be strong but balanced. Light levels should be increased, focused towards the task performance areas that require well seen small details, and adding devices or greater intensity lamps near the place of these tasks. Even though older people become more sensitive to light, very high brightness levels can be uncomfortable or even incapacitating.
- Reducing glare and reflections. Avoid direct view of lamps, using interior blinds or curtains to minimize glare from the windows; the shiny surfaces of objects can produce many reflections, which are more keenly felt when the luminous object is seen against a dark background; a source of bright light that is well protected from sight can provide good lighting in a room and minimize situations of intense glare.

Examples include indirect lighting located in architectural features such as crown moldings or niches, or luminaires having protection elements such as grids or deflectors.
• Uniform, minimizing the dark areas within an interior space. A general light or "ambient light" should ensure that there are no dark areas. Interiors should be sufficiently enlightened to allow good visibility so that people can move without risk.

• Improve perception of color, using lamps with good color rendering properties to help perceive them well. For good color, use a bulb or tube, with a color temperature in the range of 2700-3500K and CRI (color rendering index) of at least 80. The CRI characterizes the way the light produced by the lamp makes the objects seem "natural." The color temperature of a lamp and the CRI, as well as the level of light affect the color reproduction; the better the quality of lighting on a task, the more "natural" colors will look.

• The large range of artificial light sources available have individual color rendering properties. Their selection should be based on the need for color recognition in the interior as well as energy efficiency. When lamps with improved color rendering are used, then all observers, including visually impaired people, will be more able to perceive contrast differences.

The illumination level throughout a building during the day and night should remain relatively constant. Special attention to light position should be given, avoiding lights to eye level, because they can be blinding, even painful for people with specific ophthalmological problems.

Should be used extra enlightenment to accentuate stairs, handrails, signage, lighting and important spots like phones; on the other hand, lighting levels should be uniform throughout the building.

Always avoid creating situations of glare and brightness by adjusting the angle of lights, to direct the beam of light out of the sight.

Artificial lighting should be located so that we could avoid shadows or silhouettes. The same for bright light sources and windows, because sharp angle limits can produce relatively large and strong shadows.

Matte finishes instead of glossy surfaces on walls, doors, furniture, handrails and floors can also help prevent glare and reflections. For example, if there is a window at the end of the corridor, the sunlight can make the floors look shiny and even wet. Glare can be mistaken for water on the floor that the person tries to step around.

Since many elderly lose some color sensitivity, good color-rendering lamps may enhance the color discrimination that remains. Incandescent lamps, including halogen, render colors very well. Many types of fluorescent lamps render colors nearly as well as incandescent lamps, and have much longer lives.

General and spot lighting are necessary for the development of some visual tasks. Some light sources can be
distracting for visually impaired people. This can make the identification of visual clues difficult. Strongly directional daylight from windows or panels can also cause problems. Colors in contrasting shades are recommended to highlight furniture, equipment and potential dangerous objects and situations.

Stairs can be dangerous without color contrasts. Small items need a bigger color difference from their surroundings to differentiate them. Shiny surface finishes are confusing and should be avoided. Large amounts of light reflected from surfaces will cause problems, reducing contrast and increasing dazzle with brilliance. Some lighting and color conditions produce glare that may create an uncomfortable environment, and some visual discomfort. Polished concrete floors can be perceived as wet, which may create an uncomfortable feeling of insecurity. Color contrasts increase visibility and good lighting conditions makes the environment attractive and safe for the elderly.

Visual Communication design objects, interior spaces, urban environments, products, signage and all kinds of visual information will be effective and easier to read. Bringing knowledge to projectual practice, applying principles of visual ergonomics, will help people to improve their quality of life, moving safely in urban environments, living comfortably on interior spaces, and reading the visual printed information with minimum effort.

9. CONCLUSIONS

The effective communication, legibility, readability and visibility of prints will depend not only of color combinations, but on the interaction of many other factors such as: shape and design of typefaces, size type, the x-height, spaces between letters (kerning), words (tracking), lines (leading), colors and contrasts between text and background, page layout, form and weight of text, avoiding confusions between letters and numbers, reading distance, lighting conditions, surface of printing paper.

As we were studying legibility concepts and color contrasts, we always had the aim to contribute with some principles to projectual practice in other areas. When including people who might normally be ignored in the design process, design objects interior spaces, urban environments, products, signage and all kinds of visually information will be effective and easier to read, not only for visually impaired people but also for all of us. These areas of knowledge will improve the design process and contribute for an inclusive and efficient design practice. So, bringing to projectual practice this knowledge, i.e., applying principles of visual ergonomics, will help
people to improve their quality of life, moving safely in urban environments, living comfortably on interior spaces, and reading all the visual information with minimum effort.

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