THE EYE AND HOW WE SEE

JOSEPH N. TRACHTMAN, O.D., PH.D.

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Physical and Virtual Worlds

A major consideration in a virtual environment is how to have a 3D experience with a 2D presentation. The 3D experience is not a theoretical consideration for an avatar, who is building, and navigating in a virtual environment. The purpose of this paper is to apply the basic, major factors of visual perception to enhance the 2D experience.

Dr. Trachtman's avatar with his "flying eyeball" in Second Life. The "flying eyeball" was one of his projects in the Virtual Worlds Certificate Course at the University of Washington.

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SALIENT POINTS

Vision Information Processing. The vision system has two major channels, with the central channel related to cognitive activity, and the peripheral channel related to non-cognitive activity. Optimally, when both channels are fully functional the result is an enhanced perceptual state.

Cognitive versus Non-Cognitive. While the cognitive information processing channel is well-known, the less-known non-cognitive information channel is equally important. The main brain center for the non-cognitive channel is the hypothalamus.

Properties of the Vision System. Typically, how clearly we see is how people assess their vision. There are many other properties including color vision, and contrast sensitivity.

Monocular Cues to Depth Perception. Currently, a virtual world is viewed on a 2D video display. The Chapter discusses 14 cues to monocular (2D) depth perception, which can dramatically enhance a build in a virtual world.

Visual Perception and Community. The vision process includes both physiological and perception components. How we relate to what we see in a virtual world is yet another vision component, particularly in relation to building a community with an awareness of ourselves and others.

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ABOUT THE AUTHOR

Dr. Joseph N. Trachtman, born in Brooklyn, New York, was a varsity-letter athlete as well as an honor student in high school and college. He received a Doctor of Optometry degree from the Pennsylvania College of Optometry, a Master of Education degree from the Johns Hopkins University, and a Master's in Vision Science from the State University of New York, State College of Optometry. He also holds a Ph.D. in experimental psychology from Yeshiva University, where the topic for his research was the use of biofeedback to reduce nearsightedness. Dr. Trachtman completed this segment of his education with a National Library of Medicine Post-Doctoral Fellowship in Computers in Medicine at Mt. Sinai Medical School, New York. Most recently, he was a member of the first class at the University of Washington's Certificate Course in Virtual Worlds.

In addition to his private practice of optometry and neurotherapy, Dr. Trachtman has been on the faculty of several colleges, where he taught courses in psychology and education. He began marketing his biofeedback vision-training instrument, the Accommotrac® Vision Trainer worldwide in 1984. Dr. Trachtman has personally provided vision training for an array of patients ranging from world-class athletes to learning-disabled schoolchildren.

He had contributed over 65 articles to professional journals, including the prestigious journal SCIENCE. Dr. Trachtman has himself been written about in the books 20/20 IS NOT ENOUGH by Seiderman and Marcus and THE GAME ACCORDING TO SYD by Syd Thrift as well as in numerous magazines, including GQ, OMNI, and EAST-WEST/NATURAL. He and his work were the health/medicine feature in the SPINOFF, an annual publication of NASA.

Abstract
How we see employs both cognitive and non-cognitive elements in the processing of visual information. In the physical world, we certainly want to see clearly; but are also sensitive to color, brightness, contrast, depth, and perspective. Two distinct vision pathways allow us to have this sensory information. One channel is the well-known cognitive pathway from the eye to the cerebral cortex. The non-cognitive, second channel is less well known, having a pathway from the retina of the eye to the hypothalamus, whose regulation includes the emotions, the immune system, brain waves, the retina of the eye, and eye focusing. Additionally, our ultimate visual image receives input from the other senses. For example, we take pleasure in seeing a plate decorated with mouth watering food, where the smells, taste, texture, and sounds add to the visual image of the meal that will be stored in our memory. Accordingly, the design of a virtual world should include all these elements of vision in the physical world: cognitive, non-cognitive, and inter-sensory input. The challenge is to be able to display in 2D the perception of 3D. The purpose of this chapter is to describe in detail all elements to provide us with a full vision.

Introduction
How we see employs both cognitive and non-cognitive element in the processing of visual information. In the physical world, we certainly want to see clearly; but are also sensitive to color, brightness, contrast, depth, and perspective. Additionally, our ultimate visual image receives input from the other senses. For example, we take pleasure in seeing a plate decorated with mouth watering food, where the smells, taste, texture, and sounds add to the visual image of the meal that will be stored in our memory. Accordingly, the design of a virtual world should include all these elements of vision in the physical world: cognitive, non-cognitive, and inter-sensory input. The purpose of this chapter is to describe in detail all elements to provide us with a full vision.

Mind-Body Dualism
The origin of modern mind-body dualism is attributed to Rene Descartes (1595-1650), where visual perception was one of his areas of interest (Amoroso, 2010). The basic question raised by Descartes was ‘that during visual perception is it the thinking process or the sensory information primary?” Descartes’ conclusion was that the thinking process was primary. Since the 17th Century, there have been numerous theories that are both pro and con of Descartes’ proposal (Wozniak, 2005).
Jumping ahead 300 years, models of perception acknowledge that vision is a combination of central (thinking) and peripheral (sensory) information. Trevarthen (1968) described the dichotomy as focal (central) and ambient (peripheral). The most contemporary understanding of vision information processing was elaborated by Livingstone and Hubel (1987, 1988), with the parvo (central) and magno (peripheral) pathways. These pathways contain separate fibers in the retina of the eye, the brain tract from the eye to the brain, and the brain itself. Answering Descrates’ may lead us closer to understanding perception of visual objects in virtual worlds, and lead us to some serious design considerations.

Parallel Processing
With the age of microcomputers, laptops, notebooks, and palmtops we have learned a new vocabulary term known as “parallel processing.” Parallel processing refers to how many channels of data the computer can process simultaneously. For example, in the "dinosaur" days, thirty thousand dollar computers processed only eight channels, whereas, today we have grown accustomed to 64 bit machines. As is well-known, the number of channels being exponentially proportional to speed of information processing. With the vision system it is the same -- the more channels we use, the faster and the more information Iwe can process, store, and utilize. A parallel processing model relating the list will now be presented (Trachtman, 1992). With virtual worlds requiring large amounts of parallel processing to maintain the visual qualities of a physical world, it is important to observe the ratio of computing power to the vision system’s power in examining the bearing of perception in a virtual world.

Model of Attention
How one pays attention in a virtual world is significant in terms of how we engage the avatar. Examining the way the brain processes information to assist attention management will give us some insights into how the physical world person maintains attention to surrounding information based on the way the eye and brain work together. How does this get carried over to the virtual world?

1. Parallel processing exists when both central and peripheral vision are processing information simultaneously. A speed reader is a great example. A speed reader must see the exact location of each word/letter (central/parvo) and at the same time be aware of all the other words/ letters on the page (peripheral/magno). This state of attention also interacts synergistically with memory and other brain functions. Great academic performers can sustain this type of attention whenever they learn.
2. Alternating processing is when the central and peripheral information are processed one at a time; some can perform the alternating very

quickly. The average college student will maintain this type of concentration occasionally getting into parallel processing; but not be able to maintain it on a consistent basis.

3. Central/parvo processing exists when only central information is being processed in a serial fashion -- only one stream of information at a time. This is what we notice with the typical analytical person.
4. Peripheral/magno processing is when only peripheral information is being processed in a serial fashion - the student can not get focused, he is easily distracted by random thoughts. This is what we note with the typical unorganized person. There is a further twist to this type of processor. Many young students have trouble getting past this stage of attention as their creative-emotional processing is dominant. Their problem is that the function of this processing channel is not quite right -- so the channel they process information with is not coding the information properly -- this is the child with a learning problem.

Table 1
Central and Peripheral Pathways

CENTRAL	PERIPHERAL
analytical	experiential
cognitive	non-cognitive
color sensitive	color blind
cortical	visceral
high luminance	low luminance
high spatial frequencies	low spatial frequencies
language	art
left brain	right brain
low contrast sensitivity	high contrast sensitivity
parvo	magno
respond slower	respond faster
shape	movement
sustained response	transient response
texture	depth

If an avatar is expected to process significant amounts of visual information quickly in a virtual environment, they likely need to be able to envision the whole environment to process it. This may imply that avatars be trained to parallel process both central and peripheral visual information.

To better understand the extent and nature of the parallel pathways, the relationship between vision information processing and the hypothalamus, a structure in the mid-brain, will now be described.

The Hypothalamus

It is important at this point to note that the hypothalamus is involved with the regulation of the majority of bodily functions, including the electroencephalogram (EEG), memory, learning, the emotions, the pituitary gland, the immune system, cardiac function, and vision (Lincoln, 1969; Swaab, 2003). In addition to the innumerable functions and its myriad connections, the hypothalamus has further wide-ranging physiological influence via the hypothalamic-pituitary-adrenal axis (HPA). The importance of the role of the HPA axis was emphasized in 1955 by Nobel Prize winners Guillemin (1977) and Schally (1977). Most importantly, what happens with one function of the hypothalamus tends to happen in other functions. For example, our emotional state affects our visual perception, and vice versa, what we see affects our emotions. Additional hypothalamic connections are made via the vision system as will be presently discussed. This implies that whatever is designed in the virtual world that affects our emotional state, may easily affect our visual perception as well. Effects such as color, lighting, enclosures, ease of movement, authenticity of the environment, all may combine to create emotional responses that can alter our visual perception and thus either increase or decrease our attention in world. Attention management in a 3D space can affect our learning outcomes.

Beginning in the 1980's, Sadun and his co-workers began publishing reports of retinohypothalamic tracts (RHT) (Sadun, Schaechter, and Smith, 1984; Schaechter and Sadun, 1985; Kenney, Weiss, and Haywood, 2003; Sadun, Johnson, and Schaechter, 1986). To date, three distinct pathways have been described. Each pathway originates at different stages of retinal processing and terminates in different locations in the hypothalamus. A recent discovery in relation to the RHT is the opsin, melanopsin. Retinal cells containing melanopsin project to the hypothalamus via the retinohypothalamic tracts (Provencio, et al, 2000; Hannibal, et al, 2002). Melanopsin is also found in melanophores in the iris and the inner brain (Provencio et al., 1998). The discovery of melanopsin greatly aids our understanding of the non-visual aspects of light stimulation, in particular, and enhances our appreciation of the interaction between the hypothalamus and the vision system, in general.

Anatomy of the Hypothalamus

The hypothalamus is located in the proximity of the geometric center of the brain. It is surrounded by several structures, most notably the pituitary gland, and the optic chiasm – where the optic nerves of each eye meet with semi-decussation. (Netter, 1964; Schmidt, 1985; and Strandring, 2004). Illustrations of the hypothalamus are shown in Figures 1 and 2.

The size of the hypothalamus is approximately 4 cm^3, with the cube root of 4 cm being 1.58 cm (Swaab, 2003). The weight of the hypothalamus is approximately 39 to 42 grams, which converts to 1.4 to 1.5 ounces or 195 to 210 carats, respectively (Jones and Lopez, 2006). The carat notation has been given to compare the hypothalamus to the largest jewelry diamond, the Star of Africa, which weighs 530 carats (Pulliam, 2004). For the sake of brevity rather than a very lengthy discussion on the components of the hypothalamus, Table 2 (Trachtman, 2010) lists the different components of the hypothalamus, with their function(s).

Table 2

Different Components of the Hypothalalmus, with their Function(s)

Structure	Function
Amygdala	depression, stress, immune system,
	memory, reproduction, salt intake, appetite
	suppression, neurotrophic properties,
	cerebral energy metabolism, vasodilator,
	cardiovascular function, respiratory
	functions
Anterior Cingulate Cortex	pain
Anterior Commisure	immune system
Anterior Hypothalamic Area	feeding, cardiovascular function, sleep
Arcuate Nucleus	appetite, feeding, growth, reproduction,
	anorexigenic, energy balance, stress,
	gastric acid secretion, water balance,
	cardiac function, blood pressure, endocrine
	gland regulation, pain, euphoria, exercise,
	neuro-muscular and -degenerative disease
Cingulate Gyrus	stress
Commissural fibers of the suprachiasmatic nucleus	epilepsy
Dorsal Hypothalamic Area	immune system
Dorsomedial Nucleus (DMN)	ANS functions, sexual functions, feeding,
	anorexigenic, energy balance, stress,
	gastric acid secretion, reproduction,
	cardiovascular function
Fornix	narcolepsy
Hippocampus	immune system, seizures, pain, stress,
	neurodegenerative disease, learning, pain,
	reproductive functions, neural injury
	and repair, salt intake, inflammation
Hypothalamus-Pituitary-Axis (H-P-A)	
Interthalamic Adhesion	sexual dimorphism
Lateral Hypothalamic Area (LHA)	sleep, appetite, drink center, reproduction,
	energy homeostasis
Lateral Preoptic Nucleus	sexual behavior
Mamillary Complex	temperature, memory, reproduction
Medial Preoptic Nucleus	sexual behavior
Median Eminence	immune system, sleep, neurotrophic
	properties, endocrine gland regulation,
	gastric acid secretion, depression,
	hepatic encephalopathy
Nucleus Basalis	cholinergic function
Nucleus Intercalatus	pain, immune system
Organum Vasculosum Lamina Terminalis	sodium regulation
Paraventricular Nucleus (PVN)	corticosteriods; NOS:injury, stress
	hypophyseal secretion, anorexigenic,
	energy balance, gastric acid secretion,
	water balance, cardiac function, blood
	pressure, endocrine gland regulation,
	appetite regulation, immune system
Periventricular Nucleus	growth, fluid and electrolyte homeostasis,
	feeding, pituitary hormone secretion,
	nociceptive
Pineal Gland	
Pituitary Gland	
Posterior Hypothalamus	sleep, feeding, hormone secretion
Posterior Nucleus	feeding
Premammillary nucleus	feeding
Preoptic Nucleus	sexual behavior
Preoptic-Anterior Hypothalamic Area (POAH)	temperature
Recessus opticus	endocrine regulation
Sexually dimorphic nucleus of the preoptic area	reproduction
Solitary tract nucleus	feeding, pituitary hormone secretion,
	nociceptive
Subfornical Organ	drinking
Suprachiasmatic Nucleus (SCN)	circadian rhythms
Supraoptic Nucleus (SON)	NOS:injury, fluid and electrolyte
	homeostasis, water balance
Thalamus	
Tubermamillary Nucleus	neurotransmitters
Ventromedial Nucleus (VMN)	feeding, body weight, stress, gastric
	acid secretion, energy balance,
	anorexigenic, pain, anxiety, learning,
	addiction, cardiorespiratory function,
	kidney function, urinary function,
	immune function, gastrointestinal function

Figure 1
Anatomical Location of the Hypothalamus

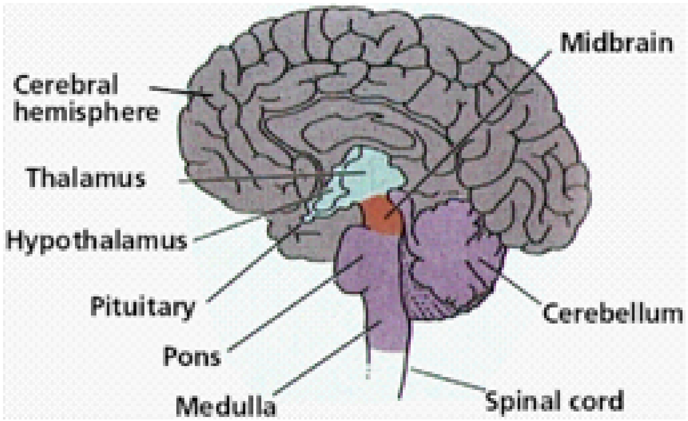


Figure 1 shows the hypothalamus in relation to the brain in general, and the mid-brain specifically

Figure 2
The Hypothalamus

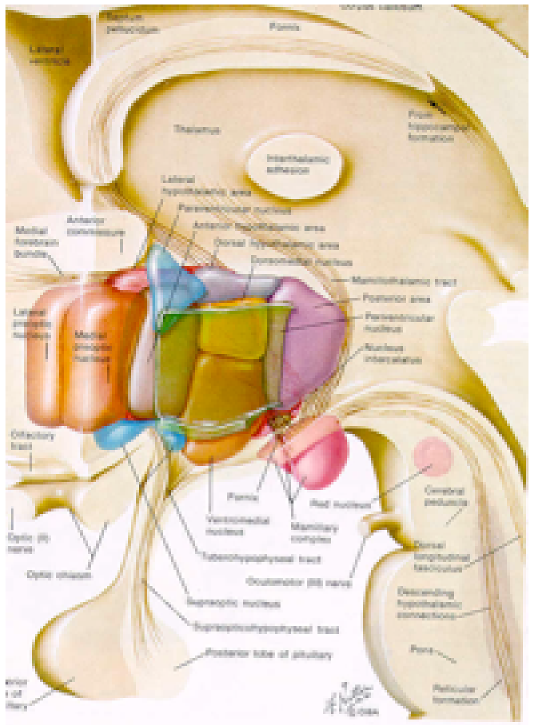


Figure 2 shows the many components of the hypothalamus

Functions of the Hypothalamus

After its initial discovery, the hypothalamus was believed to play a minor or subservient role in nervous system function and regulation. Recent studies report quite the contrary; the hypothalamus is the main component of the sympathetic nervous system, regulates much of the pituitary's activity, and produces many of the nervous system's neurotransmitters and peptides. Emphasizing the important and central role of the hypothalamus in the sympathetic nervous system (SNS), Hess summarized the many functions of the hypothalamus known at that time (Hess, 1949).

In addition to the innumerable functions and connections illustrated in Tables 2, the hypothalamus has further wide-ranging physiological influence via the HPA. The complete literature describing the HPA is encyclopedic and outside the realm of a brief literature review.

Vision Pathways

To help understand the myriad connections between the vision system and the brain, a diagram has been configured (see Figure 3). It is important to note that the connections have been limited to certain structures, which have been

As can be noted in Figure 3, fibers from the optic nerve (ON) make their connection in the lateral geniculate nucleus (LGN), and the hypothalamus (HYPO) via the retinohypothalamic tracts (RHT). Fibers from the LGN make connections with the visual cortex, and the HYPO, and then the superior cervical ganglion (SCG). (Duke-Elder and Wybar, 1961; Foxe and Schroeder, 2005). Completing the feedback and feedforward connections are the: parasympathetic nervous system (PNS) and motor input via the III Cranial Nerve, and the sympathetic nervous system (SNS): via the short and long ciliary nerves (Davson, 1990). In addition to actual neural connections, an important fact to keep in mind is that most neuropolypeptide, cytokine, and nitric oxide activities are controlled by the HYPO either directly or via its numerous interconnections (Kastin, 2006).

The purpose of the above discussion about the hypothalamus, with emphasis on the vision system, is to explain importance of our visual perception on the rest of the bodily functions. In regard to a virtual world, we are primarily concerned with the hypothalamic regulation of emotions, learning, and memory.

Figure 3
The Vision Pathways

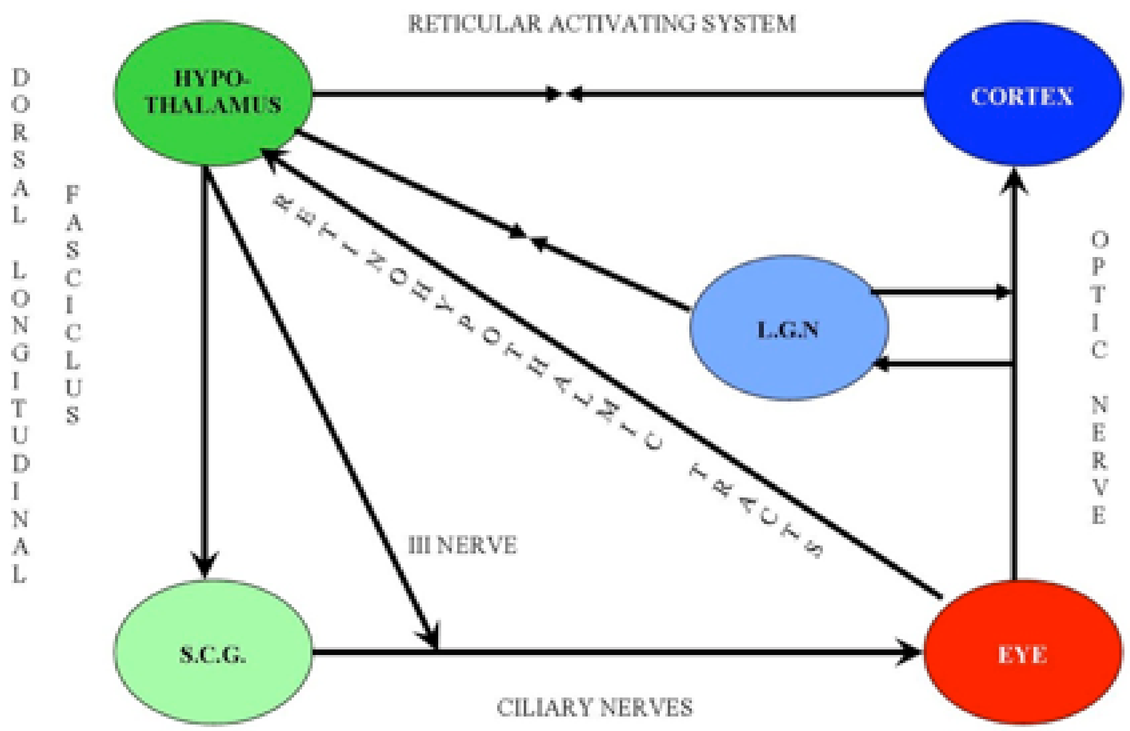


Figure 3 shows the two main pathways from the eye to the brain. One pathway goes to the LGN, and then on to the cerebral cortex. The other pathway goes to the hypothalamus, and the SCG.

Augmented Reality

The man-machine interface is a classic topic, particularly in regard to computers (Bejczy, 1980). One area of the man-machine interface confronting a virtual world is how to relate real world images to computerized images. This challenge has been referred to as augmented reality (Wikipedia, August 9, 2010, Augmented reality; http://en.wikipedia.org/wiki/Augmented_reality). Some of the challenges that arise include matching real world colors of familiar objects, the use of shadows, and the affect of the viewer's movements on what is seen on the computer display. Rothfarb and Doherty (2007) note some helpful suggestions in regard to these challenges:

- Make the environment interactive – both individually and socially.
- Care must be taken when changing the scene orientation and/or perspective (Tcheung, Gilson, and Glennerster (2005).
- Use textures to add to existing perceptual cues
- Employ multi-sensory input; typically visual and auditory, however, smell has recently become available (O'Brien, 2010). (http://www.albertalocalnews.com/reddeeradvocate/news/local/A_virtual_world_to_see_hear__and_smell_101154339.html)
- Provide viewers with a wide variety of controls to change the visual perspective on the computer display.

Additional aspects of augmented reality have been described by:

Schalk (2008) and Straw (2008) suggest using parallel processing to augment brain-computer symbiosis, as this replicates vision and brain processing.

Gorini, et al. (2008) suggest that interaction between the physical world and the virtual world will augment perceptual and social experiences.

Boules and Burden (2007) recommend the use of multiple colors to augment visual perception, and give as an example Google Earth.

Zachs, et al. (2007) discuss the importance of perceptual expectations based on prior experience. For example, it is expected that objects fall at 32 feet/second, and people to walk at approximately three to four mph. and cars speed along at approximately 60 mph

Ziemer, et al. (2009) recommend a five to seven minute period of adaptation when going from the physical world to a virtual world. Inferred from their research is that it may be helpful to have viewers make distance judgments in a virtual world as they adapt to a virtual world.

Kelly, et al. (2008) note that here are individual perceptual abilities, whereby some viewers will be more perceptually astute in a virtual world than others.

To better understand the application of augmented reality to a virtual world, the components of vision will now be discussed.

Components of Vision

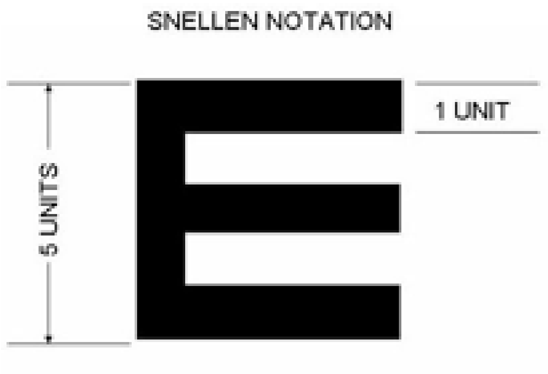
In considering the design of a virtual world, it is essential to consider the various components of vision. It is not enough to build something that "looks nice"; but is it easily seen, recognized, and integrated into our learning and experience?

Visual Acuity (VA)

VA is the best known and most common vision component, and is usually measured on an eye chart or as a projected image on a screen (Colenbrander, 2001). The letters on a standard eye chart are in a format known as Snellen notation (Lit, 1968). Snellen notation is based on the overall size of a letter subtending being five times that of the thickness of the lines that comprise the letter. Although VA can be used at any distance, the standard distance is six meters (approximately twenty feet) for distant vision and 35.56 cm (14 inches) for near vision.

The notation for Snellen VA is in a fraction, with the testing distance in the numerator and the proportional angle in the denominator. The generally accepted standard for “normal vision” is 20/20, the testing distance is 20 feet, where the letter subtends 5’ of arc. As an example, 20/200 means that the testing distance is 20 feet, the numerator, and the letter subtends 50’ of arc (200/20 =10; 10*5’ of arc = 50’ of arc), with 200 the denominator. Another way to understand the notation, 20/200, is that what a standard observer can see at 200 feet, the person being tested can see the same letter at only 20 feet. The definition of legal blindness, based on VA, is that someone sees less than 20/200 with their better eye with their best eyeglass or contact lens prescription. VA is routinely measured in ‘normal room light” with the right eye, then the left eye, and then both eyes together. The procedure is the same for both distance and near VA testing. The classic instrument for Snellen VA testing, using the ascending and descending method of limits, was the Clason projector, which allowed a continuous change in the letter size without having to change slides (Callaway & Thompson, 1953 and Borish, 1954), which went out of fashion in the 1960’s and was relatively expensive. Currently, a variety of instruments are used to measure visual acuity ranging from computerized projectors to printed eye charts (www.calcoastophthalmic.com and www.lombartinstrument.com). The testing distance for visual acuity is 20 feet.

Figure 4



Snellen Notation

Snellen Notation is a format where the over-all size of the letter is five times that of the width of the parts of the letter.

Color Vision

We appreciate color vision by stimulation of the cone cells of the retina. There are three different types of cones, S (short wavelength for blue color), M (medium wavelength for green color), and L (long wavelength for red color). It is the interaction of the three types of cones that allow us to see a rainbow of colors. We are most sensitive to a wavelength in the M cone, a lime green color, 555 nm (Merbs and Nathans, 1992).

An illustration of the perceptual effects of the physiological bias towards M cones is the difference between Fuji 35 mm film and Kodak 35 mm film.
A most interesting aspect of the use of color perception is illustrated with the rise of the use of Fuji film and the decline in the use of Kodak film (Desmond, CNNMoney, October 27, 1997). While price may be a factor, it will be noted in the following photographs and discussion, that the Fuji film is more perceptually appealing that is Kodak film.

Figure 5 is of two photographs, where both photographs were taken of the same scene just minutes apart with the same settings on a 35 mm camera (Nikon F2, Nikkor Zoom 80~200 mm set at 200 mm and focused for ∞, f16 at 1/500 sec. The top photo was taken with Kodak 400 film (Ultramax), and the bottom photo was taken with Fuji 400 film (Superia X-tra). As can be noted the Kodak film has a bias towards reds, and the Fuji film has a bias towards to the greens. Additionally, the Fuji film has better contrast and more accurate in the blues than does the Kodak film.

Why and how is this important? An answer to this question can be found in Figure 7, which shows the relative sensitivity of the human eye to the visible light spectrum. It is readily noted that the human eye is most sensitive to a lime green color, wavelength 555 nm. Accordingly, the green bias in the Fuji film is more perceptually appealing to the human eye than is the Kodak film, particularly when compared to the much reduced sensitivity to red colors of the Kodak film. This concept is very important to keep in mind in designing and using colors in a virtual world.

Figure 5
Kodak versus Fuji film

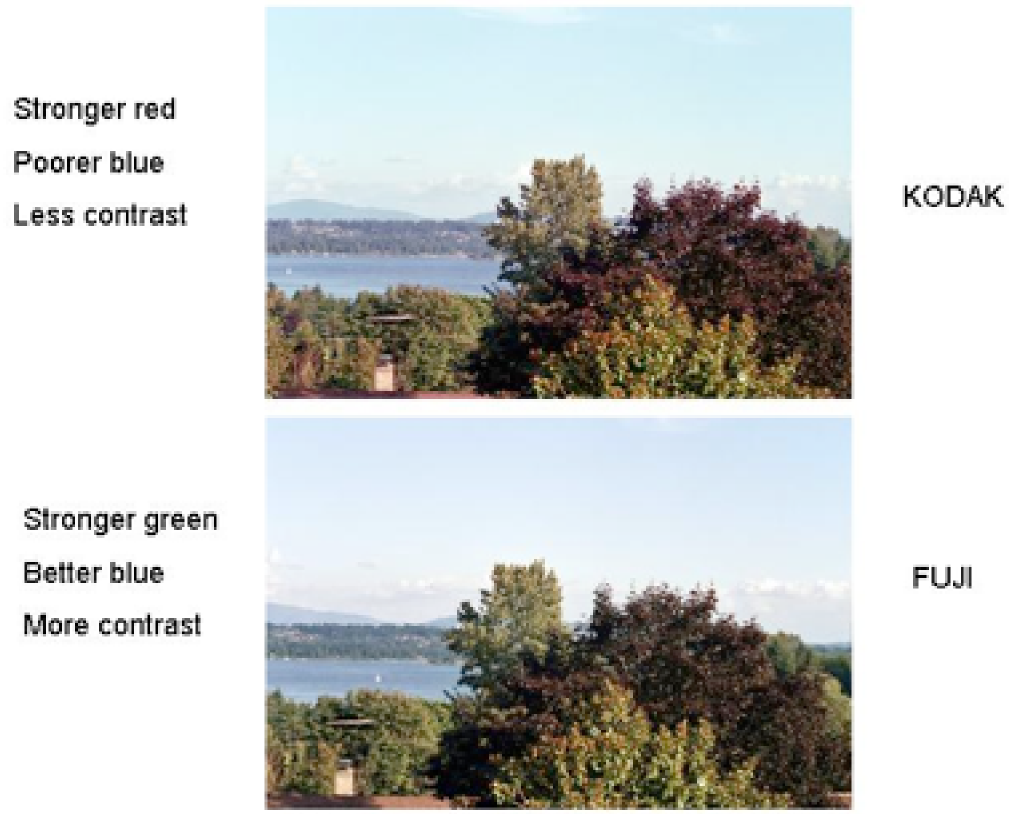


Figure 5 demonstrates the difference in color bian between Kodak and Fuji 35 mm film. The bias for the Kodak is in the red color range, and the bias for the Fuji is in the green color range. As will be noted in Figure 6, human color vision is maximal in the green color range.

Figure 6
Spectral Sensitivity Curve

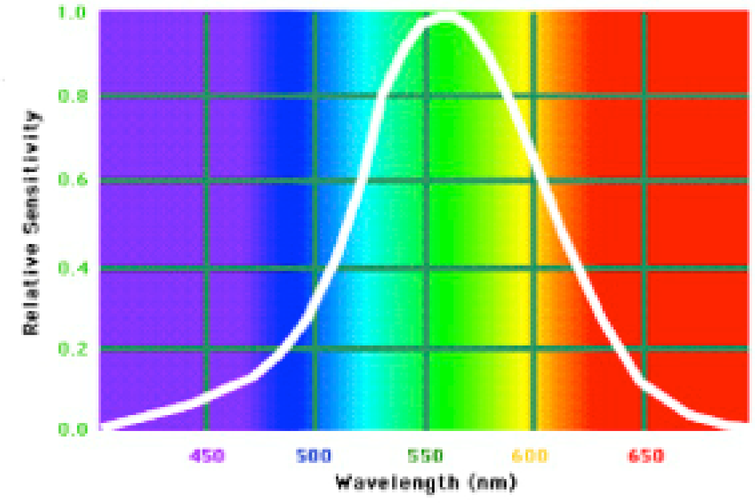
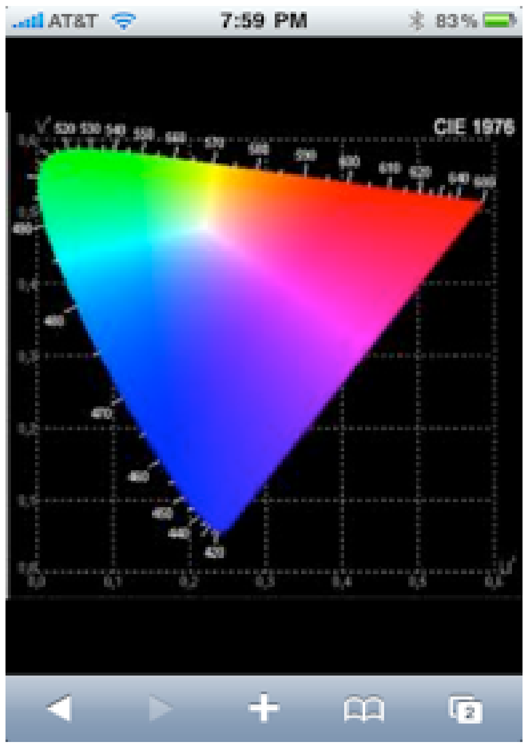


Figure 6 shows the relative brightness to the different wavelengths of light, with 555 nm being the wavelength that we are most sensitive.

Figure 7
The CIE Diagram



The CIE diagram helps us understand the relationship among the colors.

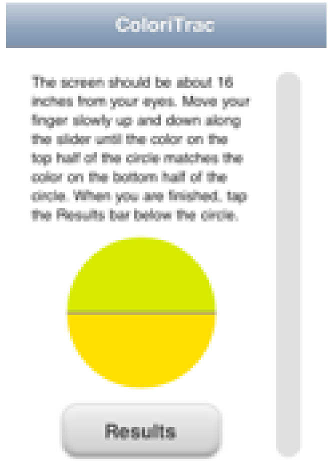
To further aid in the use of colors, reference can be made to the CIE diagram (http://hyperphysics.phy-astr.gsu.edu/hbase/vision/cie1976.html). Looking at the intersection of the blue, red, yellow, and green colors, a white area is noted. Taking this as a reference point, we can now determine complimentary or contrasting colors. For example, if we take a blue light at 450 nm and draw an imaginary line through the reference point, we note that a yellow color, 570 nm, is the complimentary color and provides the most contrast. Accordingly, we can use the diagram as an aid to determine what color combinations will provide optimal or lesser contrast.

Another important consideration in the use of color is the fact that there are people who are color blind; approximately 9% of males, and 0.5% of females (Graham, 1966). The most common color vision defect is red-green discrimination, and is known as protanomalous trichromacy, when it is a red defect, deuteranomalous trichromacy, when it is a green defect (Graham, 1966; Squire, Rodriguez-Carmona, Evans, and Barbur, 2005). The “gold standard” for red-green color vision testing is the Nagel anomalosocpe (Williams, 1915 and Birch, 2008). The test consists of a circle that can range from 1º 15’, 2º 10’, and 3º 15’ in diameter and split with a horizontal line (Lakowski, 1969). A fixed yellow color, 589 nm is on the bottom half, with the top color being a mixture of red, 670 nm, and green, 546 nm (Squire et al., 2005). The goal for the patient is to adjust the red-green mixture to match the given yellow standards. The test result is given in a range, with 45 to 73 indicating protanomalous trichromacy, and 0 to 35 indicating deuteranomalous trichromacy. A new version of the Nagel anomaloscope is a pc-based version (U.S. Patent No. 4,798,458). The test distance for the color test is between 16 to 24 in. We have recently turned the Nagel anomalosocpe into iPhone Apps, known as the ColoriTrac App, and the ColoritracB App. With this in mind, if there is extensive use of red and greens, a certain amount of the population will not be able to appreciate the colors. See Figure 8 - 10.

Contrast Sensitivity Function (CSF)

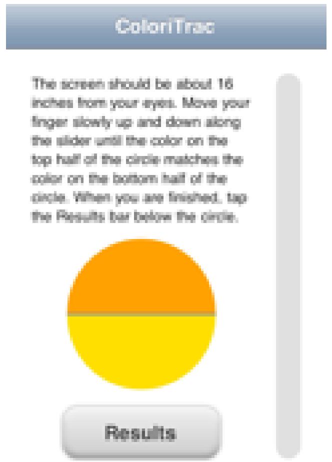
CSF is a relatively new clinical test that became popular in the 1970’s (Campbell, Hess, Watson, & Banks, 1978). CSF measures a person’s ability to discriminate spatial frequencies which is important in object recognition. To accomplish this measurement spatial sine waves are used. The human eye is most sensitive to the spatial frequency of 6 cycles per degree (Watson, Barlow, & Robson, 1983). To measure CSF, charts of varying spatial frequencies are used, and a contrast between alternating black and white strips is presented. By using the ascending and descending method of limits to vary the contrast, an accurate threshold can be obtained for a given spatial frequency. Typically the range of 0.5 to 32 cycles per degree is measured, with 0.5 cycles per degree being wide stripes and 32 cycles per degree being very narrow stripes. Clinically, only five to seven spatial frequencies are measured. A decrease in perceiving higher spatial frequencies indicates refractive disorders. A decrease in perceiving lower spatial frequencies indicates visual pathway dysfunction (Regan & Neima, 1984). The testing distance for CSF is 20 feet.In a design in a virtual world CSF becomes a critical factor in the use of lines or gratings, with 6 cpd being the most sensitive graphic.

Figure 8
Nagel Anomaloscope (ColoriTrac App)



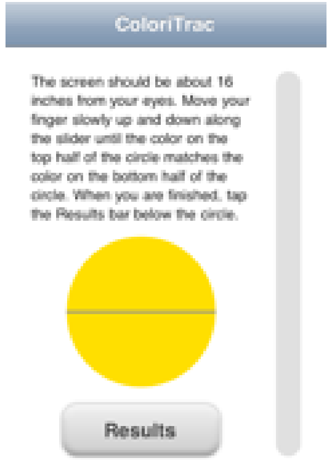
The top is in green (546 nm), and the bottom in yellow (589 nm).

Figure 9
Nagel Anomaloscope (ColoriTrac App)



The top is in red (670 nm), and the bottom in yellow (589 nm).

Figure 10
Nagel Anomaloscope (ColoriTrac App)



The top and bottom are matched exactly at 589 nm.

Contrast Sensitivity Function (CSF)

CSF is a relatively new clinical test that became popular in the 1970's (Campbell, Hess, Watson, & Banks, 1978). CSF measures a person's ability to discriminate spatial frequencies which is important in object recognition. To accomplish this measurement spatial sine waves are used. The human eye is most sensitive to the spatial frequency of 6 cycles per degree (cpd) (Watson, Barlow, & Robson, 1983). To measure CSF, charts of varying spatial frequencies are used, and a contrast between alternating black and white strips is presented. By using the ascending and descending method of limits to vary the contrast, an accurate threshold can be obtained for a given spatial frequency. Typically the range of 0.5 to 32 cycles per degree is measured, with 0.5 cycles per degree being wide stripes and 32 cycles per degree being very narrow stripes. Clinically, only five to seven spatial frequencies are measured. A decrease in perceiving higher spatial frequencies indicates refractive disorders. A decrease in perceiving lower spatial frequencies indicates visual pathway dysfunction (Regan & Neima, 1984). The testing distance for CSF is 20 feet.In a design in a virtual world CSF becomes a critical factor in the use of lines or gratings, with 6 cpd being the most sensitive graphic. See Figures 11 and 12.

Figure 11
Contrast Sensitivity Function

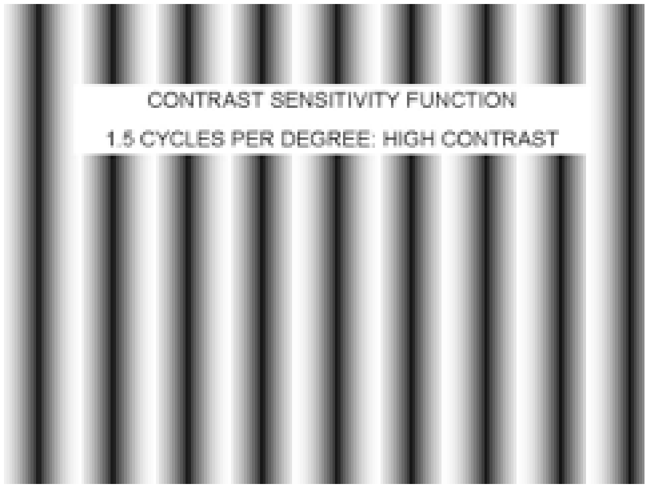
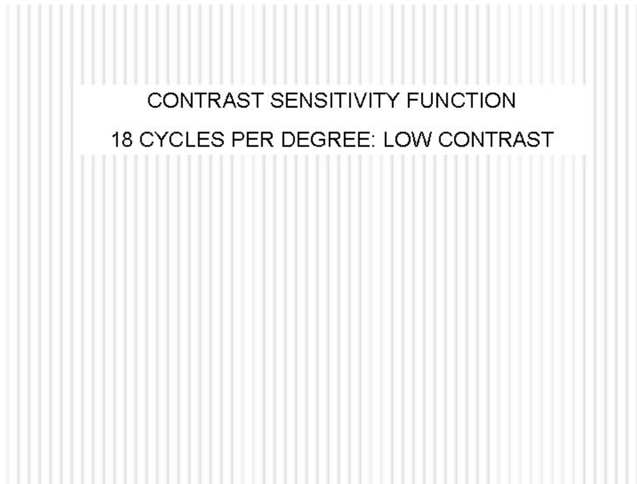


Figure 12
Contrast Sensitivity Function



Depth Perception

There are many cues to monocular depth perception such as parallax, superimposition, and size (Graham, 1966; and Cornsweet, 1970). Clinically, binocular depth perception is measured to determine if there is a balanced use of the two eyes. Binocular depth perception is perceived when an object is seen from a different perspective (angle) for each eye. According to recent articles, the TNO stereotest (Lameris Ootech BV, Nieuwegein, Netherlands) is the most reliable clinical test of depth perception (Garnham & Sloper, 2006; and Schmidt et al., 2006). The test uses random dot stereograms (Tyler & Julesz,

1980) and red green glasses. There are a series of images when seen with both eyes that appear to be above the page. The images vary in disparity, and those with the greater disparity are seen more readily that those with less disparity. Disparity between the images is measured in seconds of arc. A standard for good binocular depth discrimination is 60 seconds of arc, and poor depth discrimination is less than 250 seconds of arc. One interesting application of stereo vision is the development of a 3D virtual library (Martin, Suarez, Orea, Rubio, & Gallego, 2009). There are several notable aspects related to depth perception and virtual worlds. One is that currently a virtual worlds displays a 3D world in 2D. Future developments will endeavor to have a 3D world displayed in 3D. Someone with little or no depth perception will have difficulty in a 3D display. The quality of depth perception is an important vision function. Accordingly, people found with poor depth perception during the testing will be informed that they should visit their eye doctor in the physical world. Poor depth perception can also lead to symptoms of eye strain, tearing, and or eye fatigue.

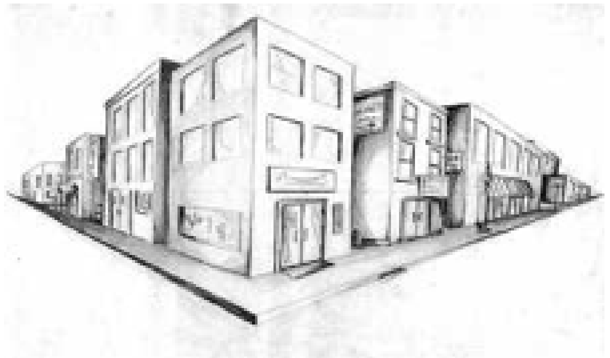
In the physical world, we depend primarily upon our binocular vision, and focusing mechanism to determine depth. In regard to binocular vision, the disparity of the retinal images, because of the separation of the two eyes, leads to fusion of 2D images into a single 3D image.

Monocular Cues to Depth Perception

The classic reference texts for information on monocular cues to depth perception are Graham (1966), and Kling and Riggs (1972). The cues are:

- Size: Familiar objects have a quality known as size constancy. For example, even though a car has a very small visual angle at 1 mile, it is still recognizable as a full size car and not a small toy.
- Shape: Familiar objects also have a constancy quality. For example, if we hold up a chair and turn it in many directions, it will still be recognized as a chair.
- Color: The color of an object helps our determination of that object. For example, if you were shown an apple that was purple it would be less recognizable than one that was red or green.
- Brightness: Objects that are closer are typically perceived as brighter than if they were far away. (PercepZone, 2010) (http://library.thinkquest.org/27066/depth/nlambiguous.html)
- Contrast: The ability to discriminate among shades of gray is known as contrast sensitivity. We are most sensitive to mid-frequency contrast, i.e. 6 cycles per degree, than to higher and lower frequencies. Additionally, if we want to make a distinction between two objects, there must be adequate contrast between them.
- Focus: This will be discussed in detail in the section of visual accommodation.
- Convergence: The movement of the eyes towards each other is known as convergence. As we change our focus, our eyes converge; the closer we focus, the more the eyes converge.
- Depth: In the physical world, we can use the disparity of the retinal images to determine depth; this is known as binocular vision. Because in a virtual world we loose that disparity, we should rely on the monocular cues to depth perception to provide a greater sense of space.
- Parallax: If there are two objects, one in front of the other, we can gain a sense of depth by the relative movement of the two images. The image closer will move more as we move our head from side to side than will the image farther away.
- Perspective: As is well known to artists, the use of two point perspective is an excellent cue to monocular depth perception.

Figure 13
Two Point Perspective



- Texture Gradient: The closer an object, the more details of its surface can be perceived.
- Superimposition: When there are two objects superimposed on each other, the object in the foreground is closer than the object that it is superimposed on.
- Moon Illusion: Objects on the horizon appear closer than objects high in the sky. Hence, the moon appears larger on the horizon than it does as it ascends.
- Shadows: When an object casts a shadow on another object, the first object is closer to the light source than the second object.

As illustrated by the 2D drawings of my office as compared to the 3D drawings, an appreciation can be made of the importance of the components of vision in making a drawing more “realistic”. The same is true in composing (constructing) a virtual world – the more simulation and stimulation of the vision system, the more it will appear that we are immersed in a physical world, rather than a purely virtual world. In order to make our virtual world like our physical world, the proper input to the vision system is required. The input from the virtual world should match the properties of the components of vision as closely as they exist in the physical world. And if possible, emotional elements are to be included. In summary, the more we make our virtual world like our physical world, the more components of vision will be stimulated.

Figure 14
Office Floor Plan 2D black and white

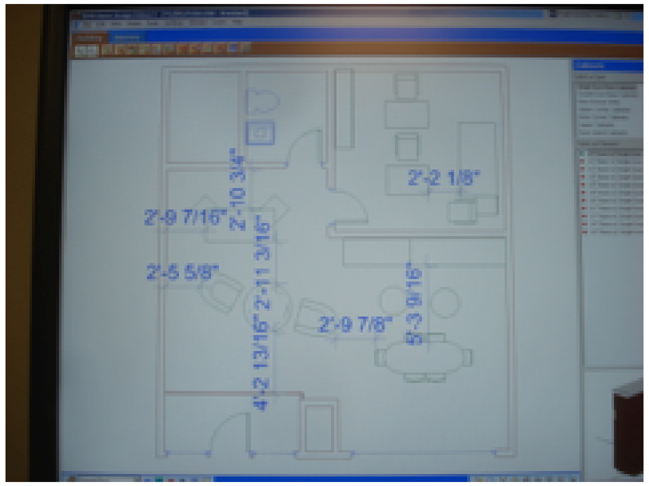


Figure 15
Office Floor Plan 2D color

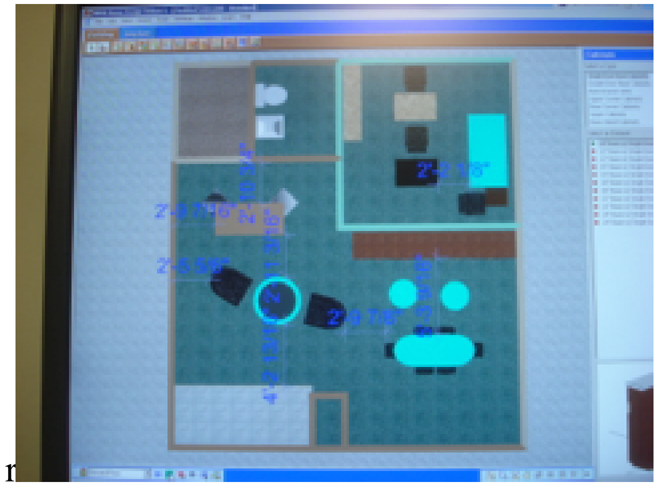
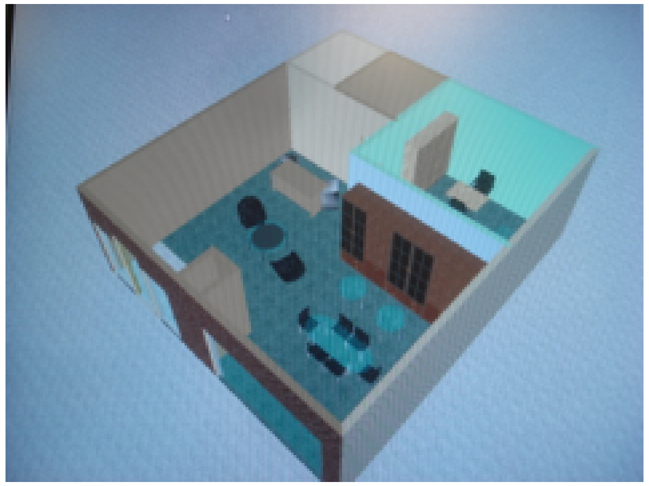


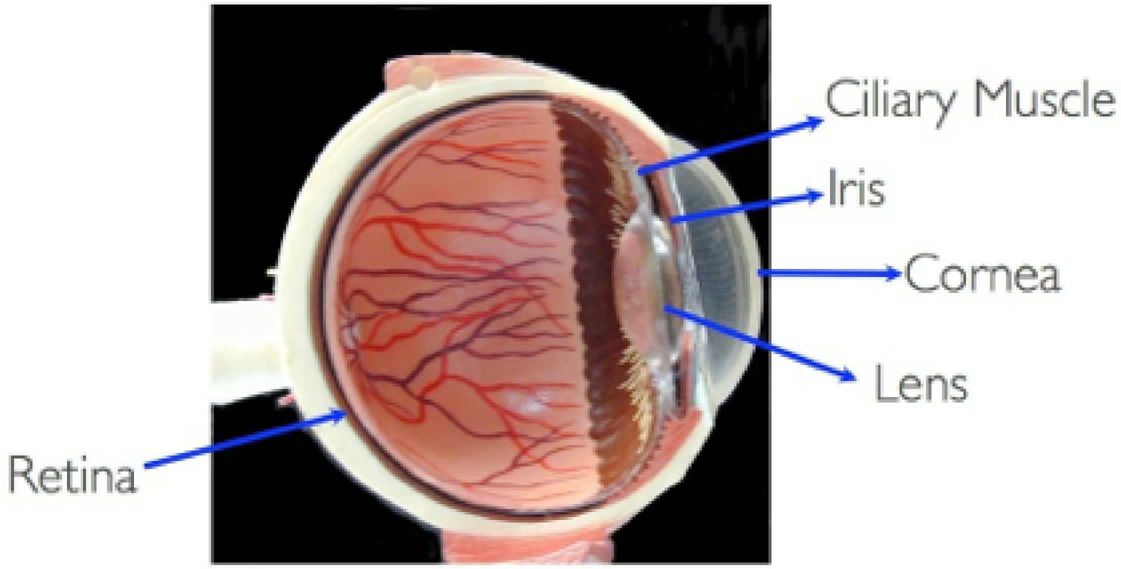
Figure 16
Office Floor Plan 3D color



Visual Accommodation

Visual accommodation is the link between the cognitive and non-cognitive visual systems (Trachtman, 1992). Visual accommodation may be defined as a change in focal power of the eye by a change in the converging power of the crystalline lens due to the action of the ciliary muscle (see Figure 17). A full understanding of accommodation will lead to a better understanding of how to present 2D data to produce a 3D effect. Accordingly, an historical view of accommodation will now be presented.

Figure 17
Diagram of the Eye



The human visual accommodation system has been a topic of interest to vision scientists since the late nineteenth century, although the topic of accommodation had it's origin of interest much earlier. Kepler (1611) had described a function of the crystalline lens that allowed a range of vision from far to near. Young (1801) was the first to demonstrate that accommodation was due to a change in the crystalline leans and not due to a change in corneal curvature or a change in the axial length of the eyeball. The cornea was dismissed as being involved in accommodation after Young placed his eye in a water lens device, thereby eliminating the refractive effect of the cornea, and was still able to accommodate. By placing rings to the sclera circumscribing the anterior and posterior poles of the eyeball, Young showed that there was no axial length increase during accommodation. If the eyeball had increased in axial length, Young would have seen a pressure phosphene. He reported that no phosphenes were seen while looking at objects at different distances.

The measurement of the change in refraction of the crystalline lens was described by Sanson in 1837 (Southall, 1961) by observing what came to be known as the Purkinje-Sanson images. These images are catoptric images formed by a light source being imaged on the anterior and posterior surfaces of the cornea and crystalline lens. Further advances in studying the action of accommodation were made by Tscherning in 1900 and Fincham (1937). Tscherning argued that the lens increases its dioptric power by increased tension on the zonules, which was a result of ciliary muscle contraction. With the increased tension, traction was put on the lens capsule causing it to flatten in the periphery and bulge in the center. According to Borish's (1970) literature review, the range of human accommodation have been reported to be from 20 diopters to one-half diopter and it inversely proportional to age.

The present mechanical model of visual accommodation in the human has been described by Toates (1972). The normal tonus of the ciliary muscle is determined by the equilibrium established between the parasympathetic and sympathetic nervous systems. For accommodation to a near object (positive accommodation) the parasympathetic nerve fibers increase their activity and the sympathetic nerve fibers decrease their activity, thereby relaxing the tension on the zonules; which in turn allow the lens to obtain an increase in dioptric value. For accommodation to a distant object (negative accommodation) the activity and the resultant dioptric change are reversed. Accordingly, stress that disturbs that balance between the sympathetic and para-sympathetic nervous systems, will adversely affect accommodation. This implies that experiencing a virtual world should be as stress free as possible.

Stark, Takahashi, and Zames (1965) reported that the accommodative mechanism acted as a non-linear system in response to stimuli and they proposed two models that could account for their experimental data. Model one was a description of a system with a flat, saturated response to large stimuli. The system was also non-linear, responding with greater changes to small changes in stimulation than for large changes in stimulation. The second model, which incorporated a decrease in sensitivity to increased blur, was similarly non-linear, has been confirmed by data reported by Toates (1972).

Another analysis of the human accommodation system was performed by Crane (1966) based on several experiments. He found that the central region of the retina, having a diameter of 30 minutes, was the relevant region for accommodative control. A control system was then described that involved feedback to the extra-ocular muscles, which control eye position to maintain fixation on the central retina. The latency of accommodation has been reported to be 100-300 msec and an accommodative change can occur at a velocity of six diopters per second (Randle and Murphy, 1974).

The application of control theory to accommodation has given new information on the activity of the accommodative system. In terms of control theory O'Neill (1969), the human accommodative system may be viewed as a non-linear, closed loop servo system, which is linked with the papillary reflex pathway and the eye movement system.

In contrast with the investigations of the 1930's and the 1940's, which had been interested in the nervous control of accommodation, other investigators were primarily concerned in the characterization of the external stimuli to accommodation. The importance of the stimuli to accommodation, which led to the recent investigations of this system, is related to the overall organization of the visual system. When the retinal role in accommodation has been defined it will lead to a better understanding of the pathways as well as the physiology of these structures. In this regard, one of the major thrusts of the more recent investigators has been to identify the various stimuli to accommodation. Accommodative responses have been elicited by a variety of visual stimuli including: blur (Fincham, 1953); target size (Campbell and Westheimer, 1959); astigmatism (Allen, 1955; Campbell and Westheimer, 1959); chromatic aberration (Fincham, 1951); and stimulus intensity (Campbell, 1953). Perhaps the most commonly accepted stimulus to accommodation by researchers is blur. Smithline (1974) concluded that: "Blur is not the sole stimulus to accommodation. It is necessary, but not sufficient." (p. 1515). However, Alpern (in Kling and Riggs, 1971) stated that current evidence suggested that any of the various stimuli to accommodation may be sufficient, but that no single one is necessary. Moreover, Cornsweet and Crane (1973) and Randle (1970) showed that accommodative responses could be elicited in the absence of all visual cues. Provine and Enoch (1975) suggested that a large range of voluntary control of accommodation can be demonstrated after training. For a comprehensive review of the literature on accommodation see Crane (1966), Tucker

(1969), or Toates (1972). In summary, the human accommodative system is the link between cognitive and non-cognitive processes, whereby an optimally accommodative system results in parallel processing.

Visual Accommodation in a Virtual World?

With the completion of the explanation of the visual accommodative mechanism, we are left with an interesting and perplexing question: How can we take advantage of the perceptual factors involved in visual accommodation in a 3D world when the images are on a 2D surface? Hoffman et al. (2010) devised a system where 3D focus cues could be displayed on a 2D screen by making the contrast of the image dependent upon the desired perceived distance, thereby simulating blur. In order to produce such an affect the authors utilized a binocular viewing system.

Accordingly, there must be some perceptual method(s) to “compensate for the lack of visual accommodation in a virtual world. Perhaps the best methods are the monocular cues to depth perception, as listed above. Of the monocular cues, two-point perspective provides the best cue(s) for virtual world accommodation with the interaction of changing depth and size. Additional monocular cues to depth perception would only aid in producing a virtual world accommodation.

A second important factor in considering visual accommodation in a virtual world, are the connections between accommodation and the hypothalamus. Visual accommodation brings into play emotional, psychological, and physiological factors into our visual perception, which certainly can be noticed when comparing a 2D black and white photo to the same scene in 3D color.

Visual Perception and Community

How does our visual perception affect our sense of community? Before directly answering this question, an analogy with alcohol myopia will be made. Alcohol myopia can be defined as the impairment – myopia – on perception and thought (Steele and Josephs, 1990). While a virtual world is not alcohol, it does exhibit some addictive behavior (Boulos, Hetherington, and Wheeler, 2007), which like alcohol can temporarily reduce anxiety and depression. Part of this myopia is the blocking of “distractions”, which can lead to possible virtual world social conflicts if someone becomes oblivious to his surroundings. Several examples can be used to answer this question. If your virtual world neighbor is a central serial processor, he certainly will have great detail in his design; but may not be sensitive to the designs of adjacent builds. If your virtual world neighbor is a peripheral serial processor, he may not be meticulous in his design or his borders; but will be aware of his neighbor’s builds around him. In other words, there should be a balance among the various perceptual factors that make a virtual world community. Colors, size, shape, etc. must all be carefully considered.

On a psychological basis, how we perceive affects our thinking. Accordingly, any building should take into consideration the builds on one’s neighbors, in particular, and the community, in general. On the other hand, there should not be such constraints as to affect creativity and someone’s desire to be an individual. However, all factors should be taken into consideration, even when it would seem unnecessary.

Summary and Conclusion

While many different topics have been discussed in this chapter, they are all related, and meant to be instructional. The goal: to describe the factors important for visual perception in a virtual world as compared to the physical world. On the one hand, if the above factors are incorporated into a build in a virtual world, they will simulate the physical world. On the other hand, if the desire is to design a build with a non-real sense of visual perception, the guidelines discussed above should not be followed.

The most essential elements in the design include parallel processing of visual information, and the lack of visual accommodation and the necessary compensation for that lack.

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LESSON PLAN

Objective: To learn parallel processing of central and peripheral vision information.

Activity: While looking at a favorite scene in a virtual world, take note of where is your vision attention, i.e. center, periphery, top left, etc. To begin learning how to parallel process visual information, look at the center of the scene. Make a mental note of the size of your vision attention, i.e. ½”, 1”, or 1 ½” diameter circle. Close your eyes and visualize the center of the scene. Gradually increase the size of the scene. Open your eyes and check to note if you accurately included what was outside the original central scene. By repeated rehearsal this exercise, you should be able to increase your visual information processing to include both central and peripheral information. It is important to understand that this may not be an easy exercise. For example, nearsighted people tend to dominate their vision attention in the center of the visual field, while farsighted people tend to dominate their vision attention in the periphery of the visual field. Why is parallel processing important? By parallel processing you will be able to engage not only your analytical skills; but your emotional intelligence as well.

Objective: Experience the relationship between the size of text and the desired perspective of depth

Activity: While most people are familiar with the depth clue of 2-point perspective; many may not be sensitive to applying an analogous concept to the size of text. For example, text in the foreground should be proportionally larger than text in the background. To better understand this concept, make two signs of the same size; placing one in the foreground and one in the background. Then type a sentence such as, “Virtual worlds rock.” on each sign using the same font style and size. Gradually change the size of the background sign with and without changing the font size. Make a note of the sign and font sizes that produce the optimal depth effect. Just one caution, make sure that the font size in the background will still be readily legible. If not, the size of the foreground font should be increased to maintain the optimal depth effect.

Objective: Experience how color affects memory and attention.

Activity: Look at the 2D picture of the hypothalamus. Report in writing what the areas of the hypothalamus are named. Now look at this picture of the hypothalamus (make sure that all of the shades of the picture are in a color or hue of red). Now report back in writing what the areas of the hypothalamus are named. Note: what did you feel when looking at the first picture? What did you feel when looking at the second picture? Did you have a harder time remembering the areas of the hypothalamus picture that was in shades of red?

Objective: To understand the concepts of perceptual constancy of size and shape.

Activity: We all know that if we take a chair and place it 100 feet away, we still recognize it at a standard size chair. This is known as perceptual constancy. The actual size of the image of the chair in the eye that is 100 feet away is much smaller that it was when it was within arm’s reach. However, we still recognize it as a standard sized chair. We now want to apply this concept to virtual reality. Make or take a chair in a virtual world scene, and duplicate it. Place one chair in the foreground and the other in the background. Being the same size, the one in the background looks a little odd in its proportion to the rest of the virtual world scene. Gradually make the chair in the background smaller until it is perceived to be in a proper proportion to the chair in the foreground.

Objective: Apply texture to augment perceptual cues in a virtual world.

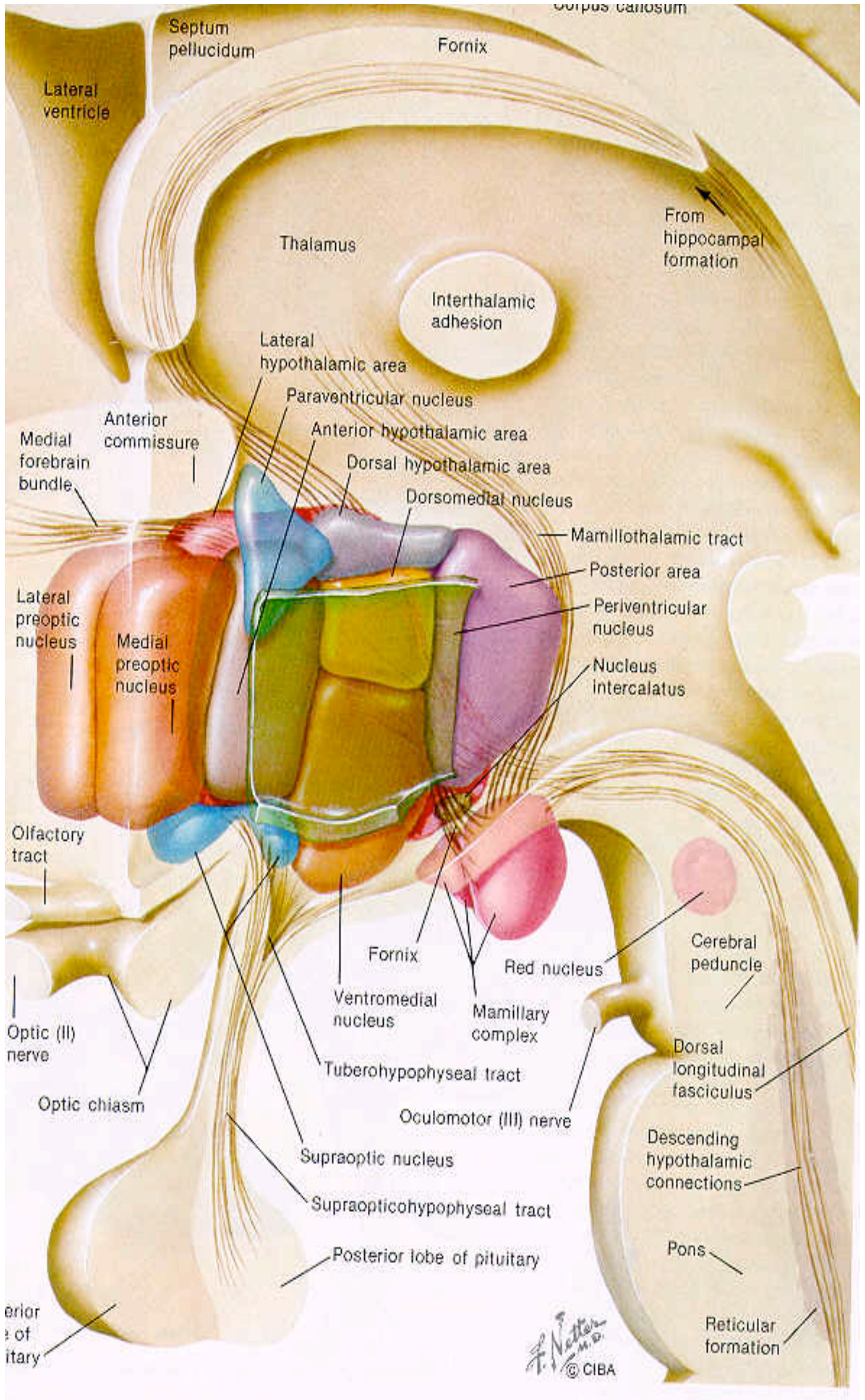
Activity: Use textures to add to existing perceptual cues, i.e. contrast, depth, visibility, etc. Perhaps this could be the key activity that you want to begin with when exploring visual perception in a virtual world. If you were going to view an object with one set of textures, then use various choices of textures to add to existing perceptual cues. Which textures would you choose and why?

Objective: To learn the perceived distance of object by varying their brightness.

Activity: Objects that are closer to us appear brighter. We can better understand this concept by demonstrating two different scenarios. First, make or take an object in a virtual world scene, and duplicate it. Place one object in the foreground, and the other in the background. Do they both have the same degree of depth within the scene? Second, make the object in the background brighter and duller, while noting the relative sense of depth as compared to the object in the foreground.

Objective: Cite how the human eye accommodates for the differences between 2D and 3D

Activity: Model of attention. Read the following paragraph as quickly as you can: "blah, blah, blah". What are the key points of the paragraph? Wait for answers. Now read the following information in a virtual world site: "blah, blah, blah". What are the key points of the paragraph? How would you design the virtual world environment so the person could speed read information while navigation through the virtual world environment


Septum pellucidum
Fornix
Lateral ventricle
From hippocampal formation
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Lateral hypothalamic area
Paraventricular nucleus
Anterior hypothalamic area
Dorsal hypothalamic area
Dorsomedial nucleus
Mamillothalamic tract
Posterior area
Periventricular nucleus
Nucleus intercalatus
Anterior commissure
Medial forebrain bundle
Lateral preoptic nucleus
Medial preoptic nucleus
Olfactory tract
Fornix
Red nucleus
Cerebral peduncle
Ventromedial nucleus
Mamillary complex
Optic (II) nerve
Optic chiasm
Tuberohypophyseal tract
Oculomotor (III) nerve
Dorsal longitudinal fasciculus
Descending hypothalamic connections
Supraoptic nucleus
Supraopticohypophyseal tract
Posterior lobe of pituitary
Pons
Reticular formation
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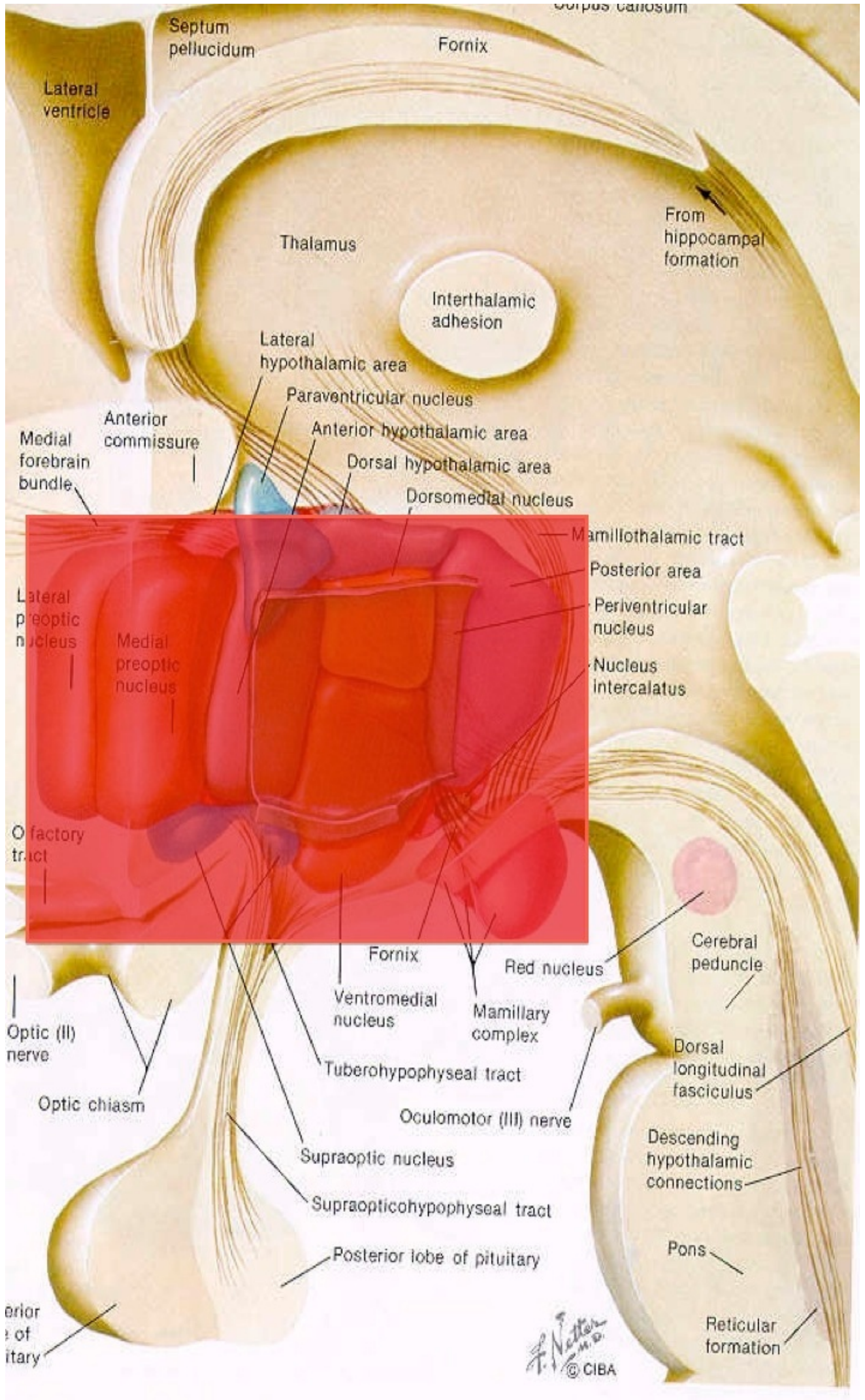
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Lateral hypothalamic area
Paraventricular nucleus
Anterior hypothalamic area
Dorsal hypothalamic area
Dorsomedial nucleus
Posterior area
Periventricular nucleus
Nucleus intercalatus
Anterior commissure
Medial forebrain bundle
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