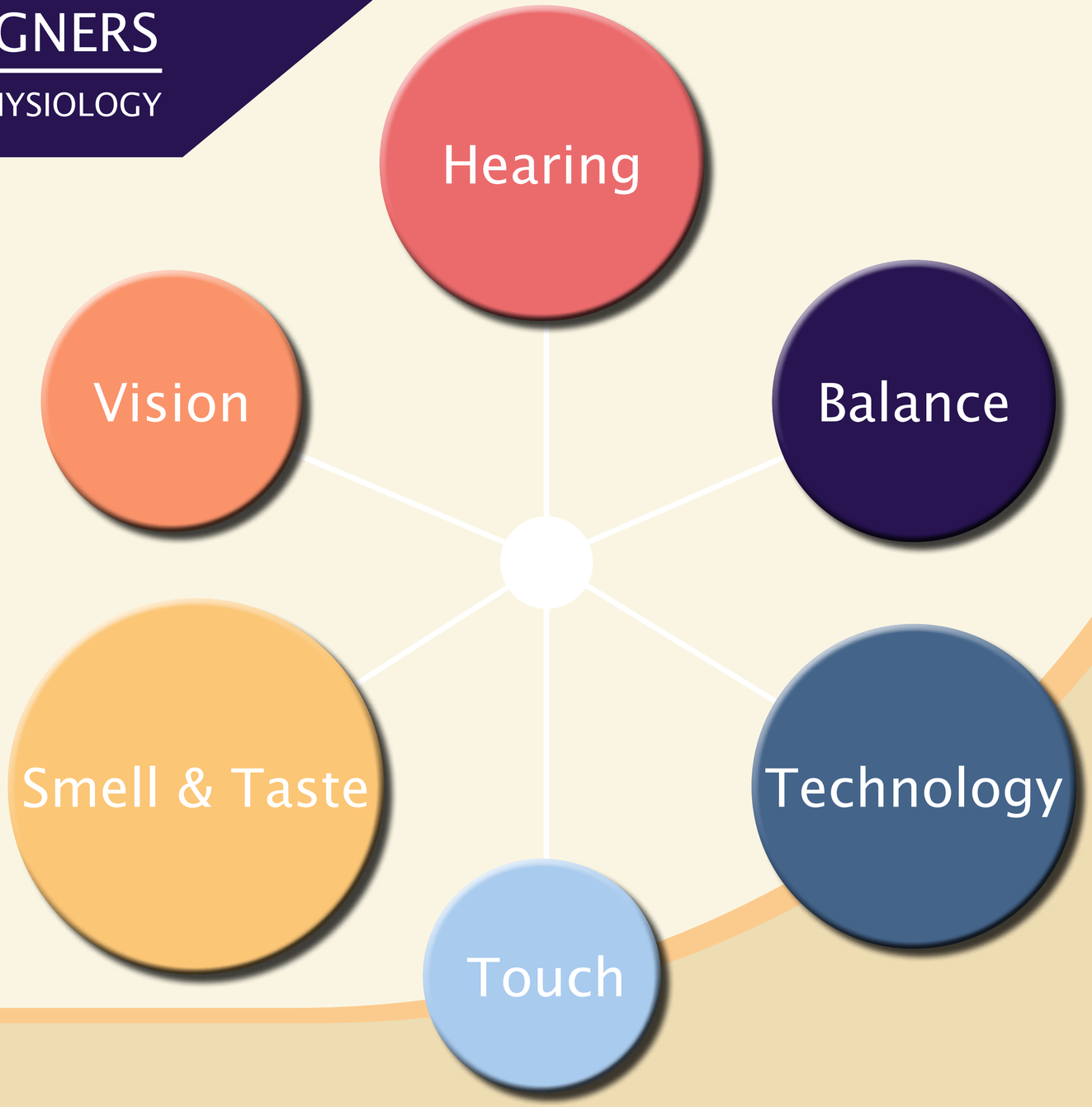
HX FOR DESIGNERS
ANATOMY & PHYSIOLOGY



Created By:
Emma-Rose Walker

Project Supervisor's:
Dr Caroline Erolin
Dr Rodney Mountain

Special Thanks:
Chris Lim
Arran Lewis

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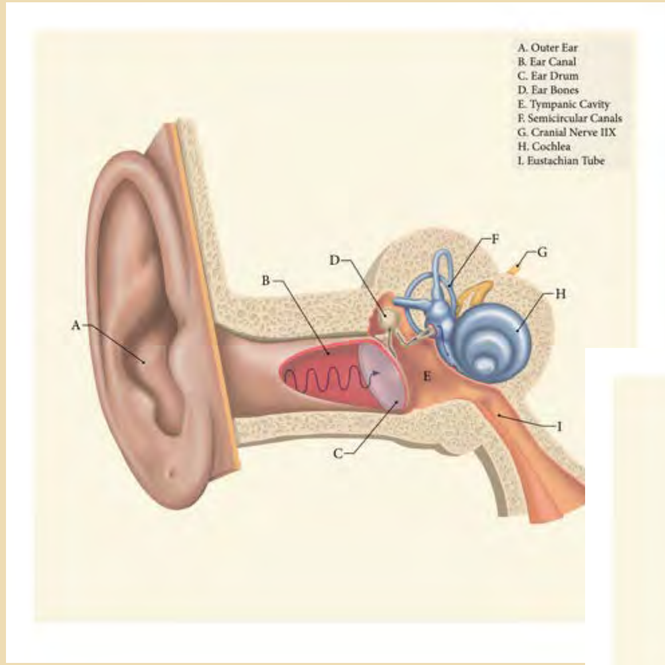
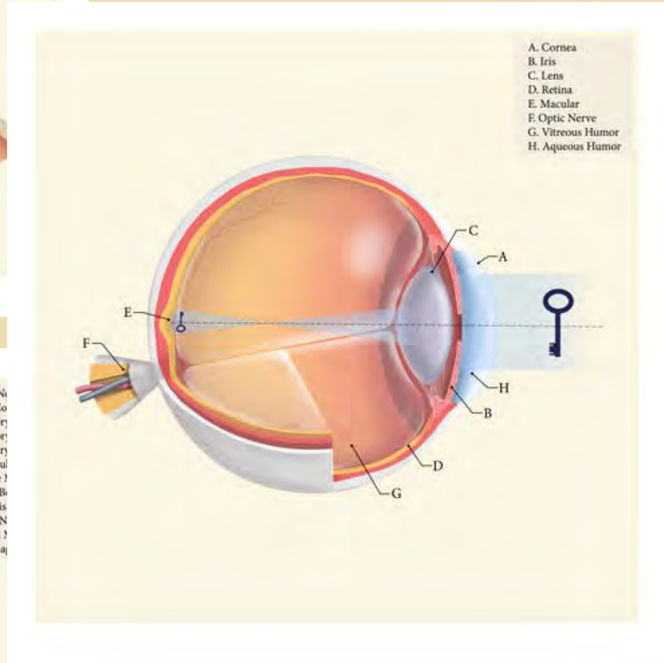
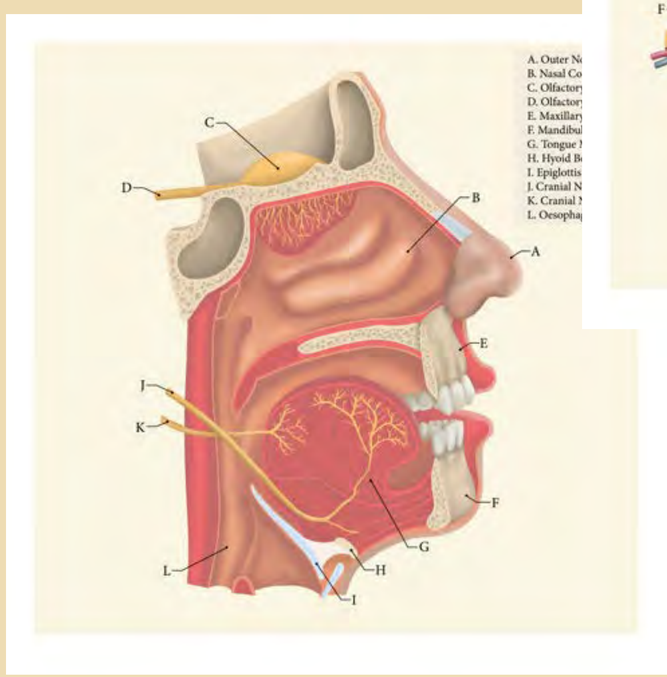
The project concept stems from a brief proposed by ENT surgeon Mr Rodney Mountain. As a guest lecturer for the MSc Design for Healthcare course at the University of Dundee, Mr Mountain expressed the need for a digital e-learning resource to accompany his lecture on human experience design. The HX lecture details how the sensory organs function, what the natural limitations of the human sensory organs are, and the most common disabilities affecting the sensory organs. The aim of the lecture is to encourage design students to consider all the senses in their future designs. This e-learning resource covers the same aspects as the lecture, with a little more detail on each of the senses intended to be revisitable by students as and when it is needed.

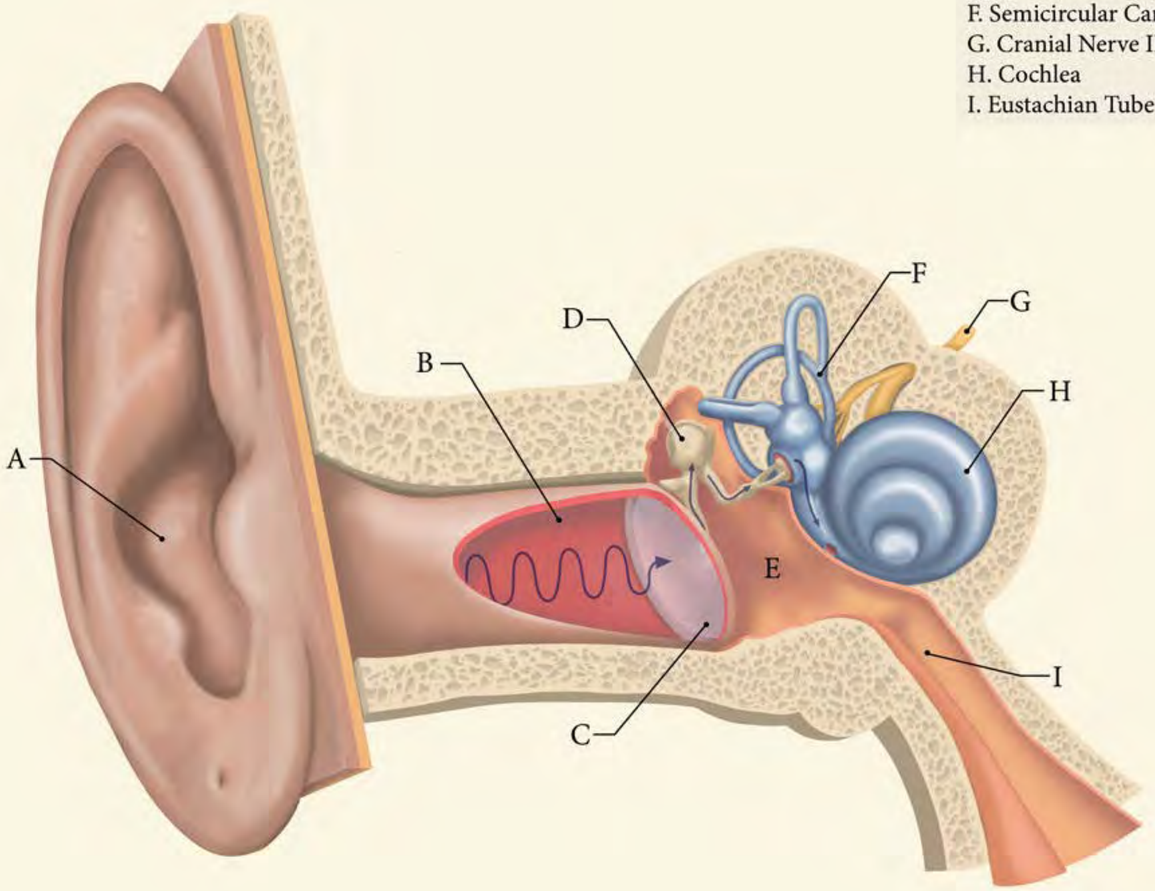




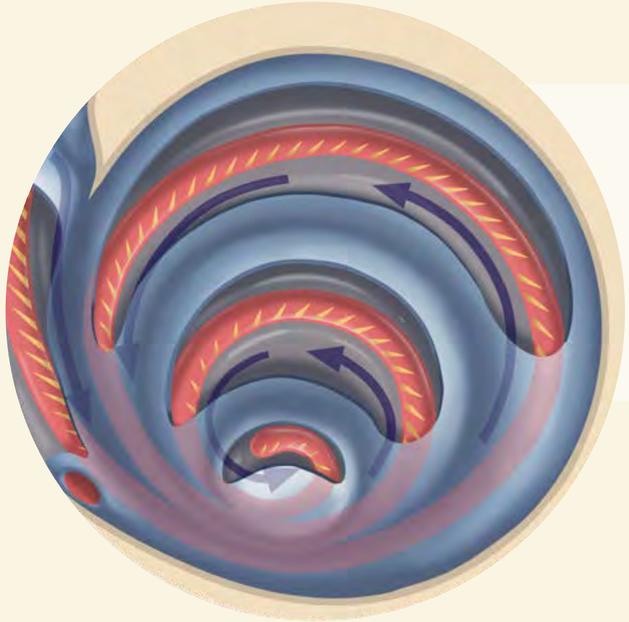


Hearing

A. Outer Ear
B. Ear Canal
C. Ear Drum
D. Ear Bones
E. Tympanic Cavity
F. Semicircular Canals
G. Cranial Nerve IIX
H. Cochlea
I. Eustachian Tube



When sound waves travel through the air, they are channeled into the ear via the pinna of the outer ear. The sound wave travels down the ear canal and causes the tympanic membrane (ear drum) to vibrate. The vibration of the tympanic membrane causes three small bones in the middle ear to move, passing the vibrations along to the cochlea.



The cochlea is a fluid filled spiral structure with tiny hairs which translate vibrations into electrical impulses, transferred to the brain for processing via the cochlea nerve.

Binaural hearing is the use of both ears to detect the direction sound is coming from, being louder in one side than the other. Being deaf in a single ear can limit how well a person percieves the direction of sounds.

The natural limitations for human hearing are between 20Hz and 20,000Hz. Normal hearing can detect sound when amplified between about 0-20 decibels, in a soundproof booth. Overall, the human ear is best adapted to frequencies between 1000 and 3500Hz (human speech covers the range of 200-8000Hz).

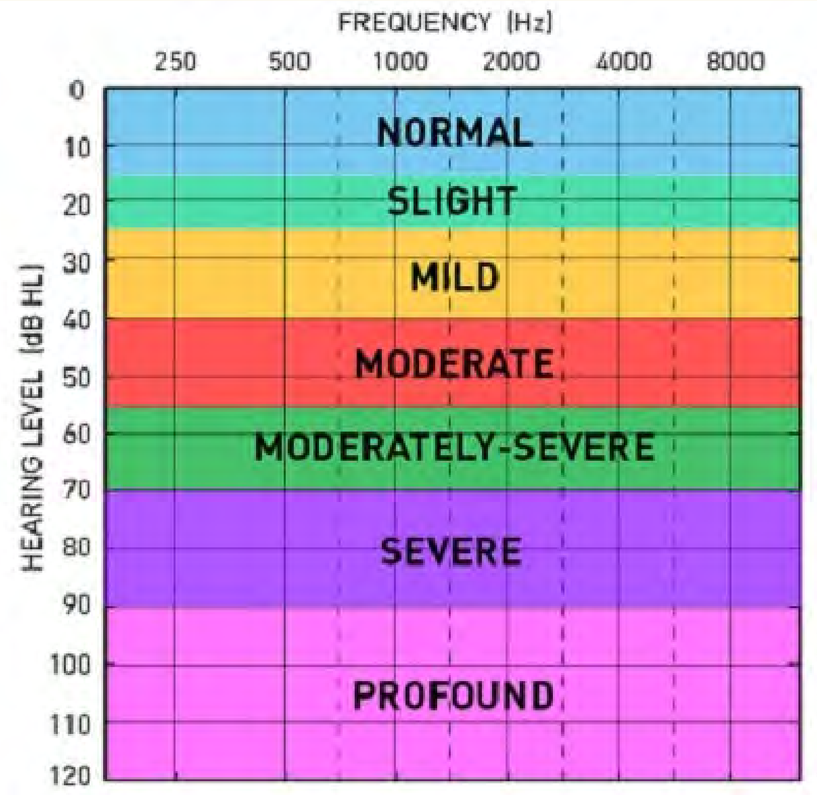


Fig 1: Audiogram of normal to profound hearing loss.

n.d. Audiiogram of Normal to profound hearing loss. [image] Available at: <https://www.babyhearing.org/what-is-an-audiogram>

In general the vowels in speech (a,e,i,o,u) are lower frequency in nature and the consonants (B, C, D, F, G, H, J, K, L, M, N, P, Q, R, S, T, V, W, X, Y, Z) that often help bring clarity to words are higher in frequency.

Common Disabilities

Presbycusis is the loss of hearing as humans naturally age, commonly losing the ability to detect higher frequency sound waves, thus losing the ability to hear higher pitch noises. Hearing loss can also occur due to acoustic trauma, often loud or high frequency noise can damage hair cells of the inner ear. Tinnitus for example is a high pitch ringing or buzzing noise in one or both ears without any external source, indicating damage to the hair cells in the cochlear.

Some children are born with hearing disabilities, often related to cochlear function. **Otitis media with effusion**, commonly called glue ear, is very common in children. The middle ear fills with fluid reducing the ability to detect low frequency sounds in the effected ear. Children affected by this condition can act out because of the deafness which occurs.

Hearing disability can also include cognitive disabilities which surround speech or language recognition. Common cognitive disabilities that influence how we perceive sound are ageing, dementia, anxiety, depression, and poor concentration caused by illness or drugs.

Designing for Hearing

When designing with sound in mind, consider that normal human talking range is around 55 to 65 Decibels with a frequency of 80Hz to 260Hz. When designing for older people ensure that the frequency of sounds is on lower end of human speech frequency as people lose the ability to hear high frequency sounds with age but also require louder sounds as the ear structures deteriorate with time. For example, the pitch of sounds at a traffic light should be low frequency in nature, as a high percentage of older people can’t hear high pitches.

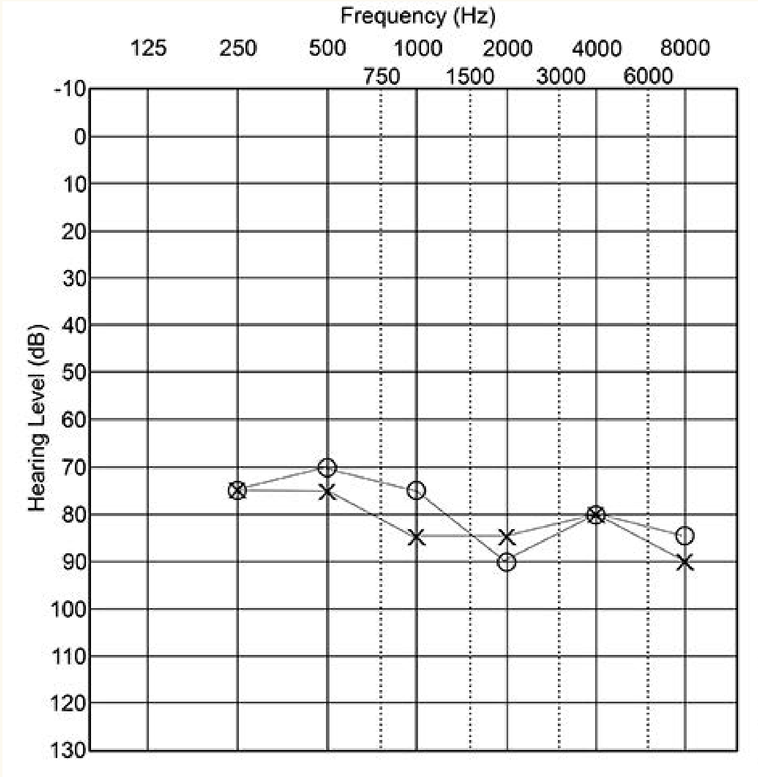


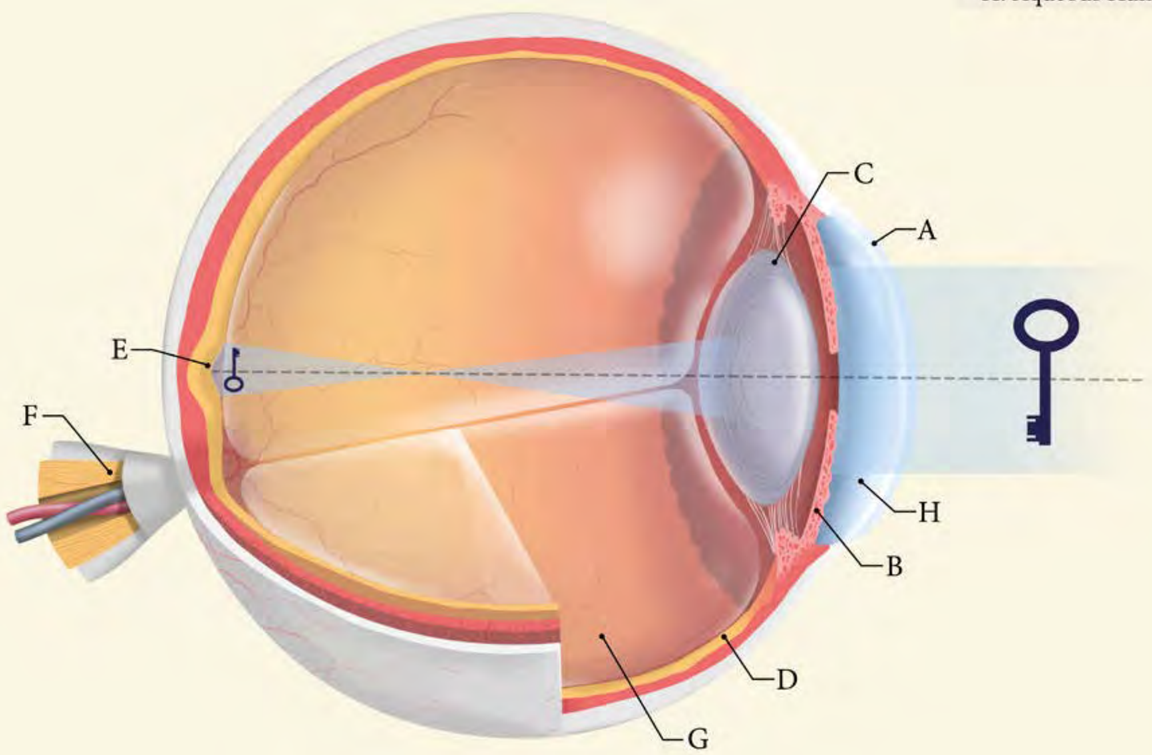
Fig 2: Severe hearing loss audiogram

n.d. Severe hearing loss audiogram. [image] Available at: https://www.babyhearing.org/what-is-an-audiogram [Accessed 26 July 2022].

Designing for children however may require higher frequency sounds to get their attention but keep the sounds closer to human speech in decibels so that children are not overwhelmed by loud noise. The designer should be aware that young children might have glue ear and will not hear mainly low frequency sounds well.

For a loss of hearing, designers could consider using design aspects to target the other senses, like vibration so people can essentially feel sound or direction of sound, attention drawing visuals and text or signs. An example of using vibration instead of sound would be the white lines on either side of a motorway, should the car drift out of the road lane, the white lines have a texture which causes a strong vibration when driven across, alerting the driver.

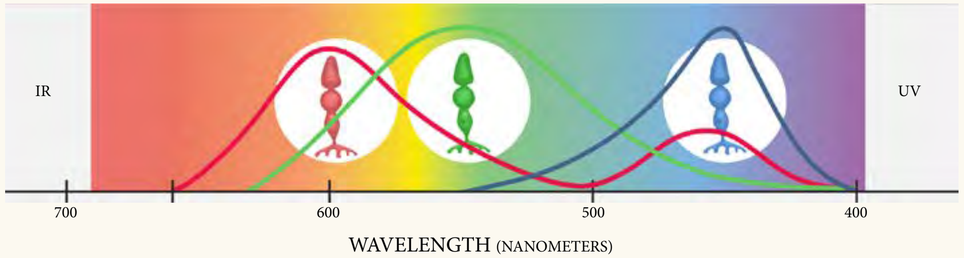
Vision



Light in the form of waves bounces off an object scattering in all directions. When one of the reflected light waves enters the eye, the cornea, aqueous humor, iris, lens and vitreous humor function together to bend the light and focus it on the retina. The retina is a thin tissue of the inner eye which contains photoreceptor cells. Rods, sensitive to light intensity and cones, which detect colour. The light information detected by the rods and cones is carried to the brain by the optic nerve. Interestingly, the lens and cornea bend the light so that it lands on the retina upside-down. This wrong way up image is processed by the brain which interprets it right-side-up.

Binocular vision is the overlapping visual range of each eye to perceive depth. A single image from each eye is relayed to the brain which compares the differences in the images creating a three-dimensional perception.

Out of the entire light spectrum, humans can only perceive a small portion of light. We call this the visible light spectrum. Human eye anatomy only contains three types of cones, being red, green and blue detecting cones, which means we cannot detect light waves such as infra-red and ultraviolet.



Common Disabilities

Humans can have many disabilities which involve the eyes, some of the most common visual impairments are refractive problems like Myopia (nearsightedness), Hyperopia (farsightedness), Astigmatism (uneven cornea curvature), cataracts, glaucoma, macular degeneration and colourblindness.

Full-Colour Vision

Green-Blind Deuteranopia

Red-Blind Protanopia

Blue-Blind Tritanopia

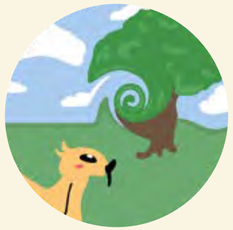
Above are some basic forms of colourblindness, though there are many more types. Colourblindness occurs in 1/12 men and 1/200 women worldwide, it is caused by the colour detecting cones in the eyes not functioning properly, this leads to a variation in the perception of colours in a person's environment.

Blue is the richest colour which is visable to most types of colourblindness, so consider using blue tones in a colourblind accessible design.

Presbyopia is the loss of close-up vision focus as a person ages. This is caused by the lens in the eye no longer focusing the light on the retina correctly. This can be corrected with glasses or reading glasses.

Glaucoma is caused by damage to the optic nerve which transfers light information from the eye to the brain, this is due to the buildup of fluid pressure in the front of the eye (aqueous humor). The peripheral vision can become blurry, and the person may have tunnel vision. The only treatment is reducing the fluid pressure to prevent further optic nerve damage. Bright lights may cause glare to those with glaucoma.

Cataracts are the clouding of the eye lens, usually in older people but could occur at any age. This clouding causes the vision to become misted and can eventually become so severe it leads to vision loss in one or both eyes.



Macular degeneration is the leading cause of vision loss for older adults. The macular is part of the retina, this becomes damaged over time leading to distorted vision. Some people with macular degeneration have difficulty performing tasks on their own due to loss of sight and require greater light levels.

Designing for Vision

Contrast between colours of objects can increase visibility, especially when wanting to draw attention to specific design features like handrails or stairs. It is good practice to design in black and white first to ensure the contrast is great enough between features. Using the light reflective value scale, a designer can ensure there is enough contrast for human visual ability and a variety of visual disabilities. Contrast in colours at the opposite sides of the colour wheel can also enhance this, however, consider that red is a very visually proceeding colour while blue is visually receding. This means colours towards the red side of the colour spectrum will be more noticeable and ‘jump out’ more than that of the blue end of the colour spectrum. When considering colour blindness, great contrast between colours can be incredibly helpful, even though these colours may be observed differently to that of a non-colourblind person, there is enough variation so that they can still perceive the contrast. When designing you should also consider environmental factors such as day and night. Designs which appear to work in well-lit environments may not necessarily work in lower light levels.

LRV Scale

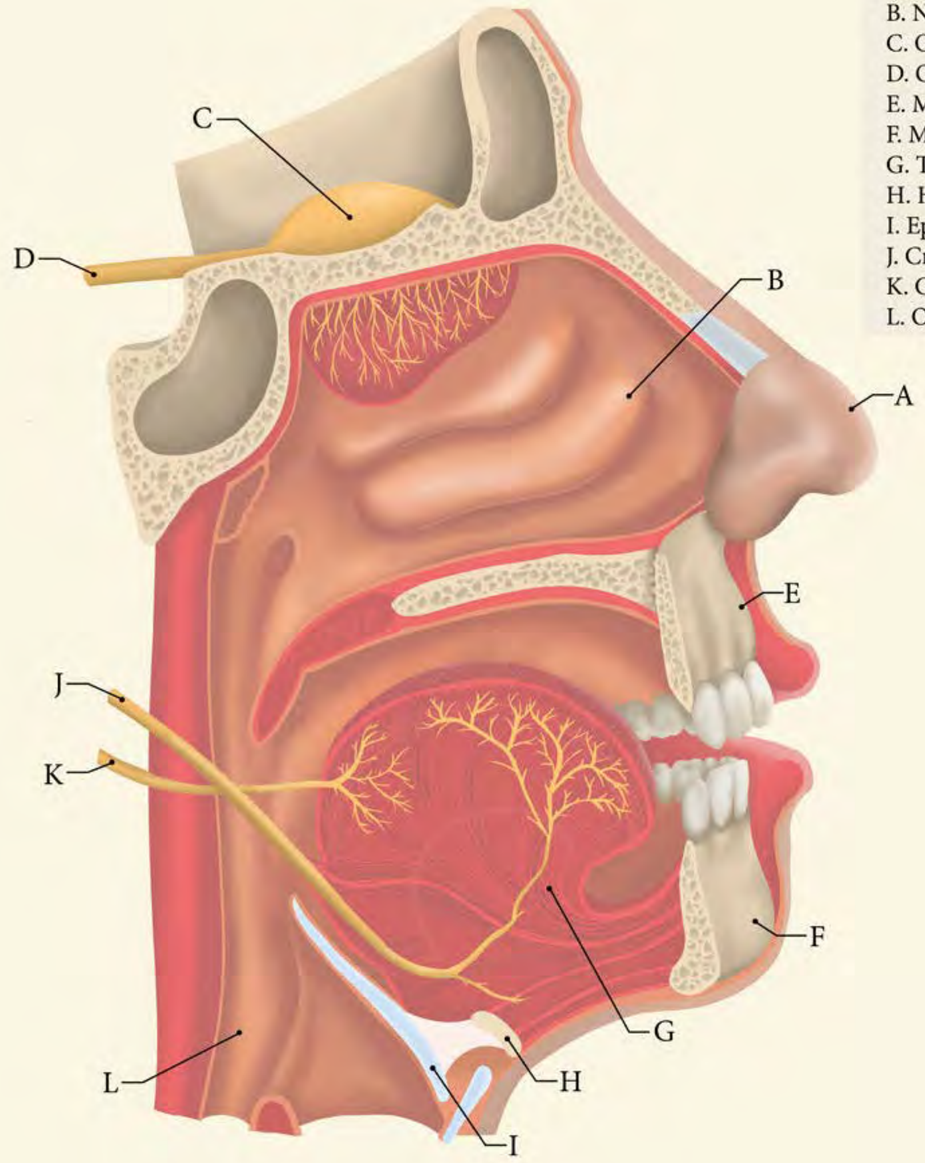
Consider using an accessibility colour checker on the colours in your designs: https://color.adobe.com/create/color-accessibility

Taking influence from nature , colours and patterns can be used to alert or warn people. Due to human evolution we react to these colours or shapes on a subconscious level, consider bee or wasp stripes as a warning, or bright colours to alert of threat or danger.

To ensure that text is legible by people of all ages, consider using size 16 or above in a San-serif font. Not only are San-serif fonts less visually complex than their serif counterparts but can also be much more legible to people with cognitive disabilities such as dyslexia and autism. The text should contrast the background it is on to ensure maximum legibility. Capital letters, font boldness or larger scale can be used to draw attention to text which should be read first.

Colours also have a variety of connotations based on culture, for example where red may signify love in one culture could signify luck or fear in another. The context which the colours are used can elicit differing responses. For example, if exit signs are commonly green in a region, then this is what people in this country are used to and will look for, but should the sign be in an uncommon colour for this region, even if visually contrasting, then it will be more difficult to follow, especially in an emergency. There are many meanings to colours, using certain colour pallets in certain contexts can elicit unintended or even negative interpretation, this is also known as the study of semiotics, the study of signs and symbols and their use or interpretation.

Smell & Taste



Senses of smell and taste work similarly and often in conjunction with each other. Smell is perceived when odor molecules enter through the nose or mouth where olfactory cells in the olfactory membrane detect the molecules sending electrical signals to the brain via the olfactory nerve.

Taste occurs when taste buds detect molecules of food on the tongue dissolved in saliva. Dependent on the type of molecule and taste bud, a variety of electrical signals can be sent to the brain via the gustatory nerve to form the perception of taste.

Common Disabilities

Loss of smell and taste can occur in a variety of ways. Trauma, dryness, infection and medications can dull or cause the loss of smell and taste sensation.

Viral infections that cause the common cold or Covid, commonly cause a reduction in the sense of smell. This is usually temporary in nature and recovers with time. Severe head injuries can tear the very fine nerves that supply smell sensation, consequently causing a complete loss of smell which unfortunately is often permanent in nature.

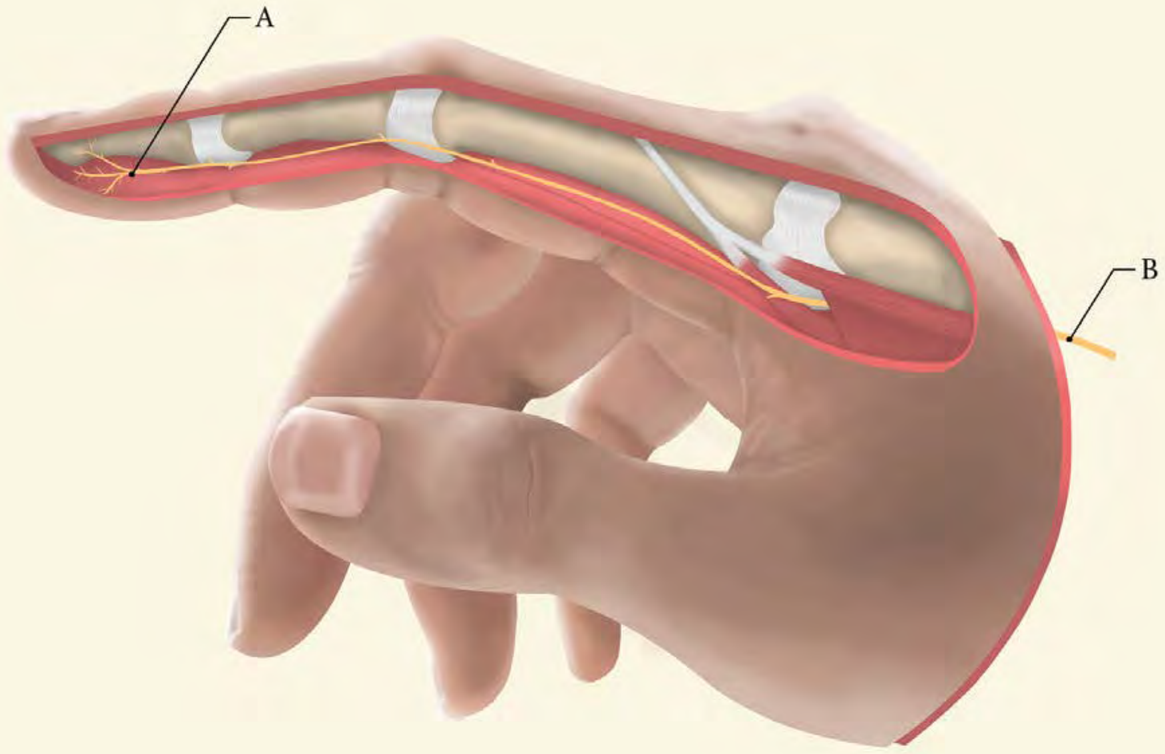
A reduction in the volume or liquid consistency of saliva can cause impairment of taste function. This can be caused by medications that have a side effect of causing dryness, or by damage caused by cancer treatment radiation given to the mouth and neck region. This radiation causes a burn to the tongue and mouth lining and often damages the saliva glands that make saliva.

Designing for Smell & Taste

Smell and taste both play a large part in memory formation. Different smells can trigger very powerful human emotional responses. ‘Good’ smells often delight and attract people, but ‘bad’ smells cause revulsion and distancing. Design for smell plays a very important part in the placement of facilities within interior environments. For example, the design of a kitchen close to an eating space, the distancing of bins and toilets, and the placement of open windows being important considerations. Windows not only bring in light, but allow for fresh cool air into a building which can improve airflow and flush out unpleasant smells. A range of symptoms described as ‘sick building’ syndrome, is often attributed to poor airflow, smells and artificial light sources within closed buildings.

Touch

A. Nociceptors
B. Nerve Pathway



Pain, touch and pressure receptors, and hair cells in the skin are triggered by contact with a stimulus, sending an electrical impulse along sensory neurons to the brain. Dependent on the type of receptors triggered the brain will perceive the electrical information in the form of temperature, texture or pressure. In the case of painful stimuli, the sensory neuron pathway diverts to the spinal cord (the central nervous system) instead of the brain, which results on a much faster motor neuron response to muscle fibers which move the body away from the painful stimuli, also known as a reflex action.

Common Disabilities

There are many ways in which loss of touch sensation can occur. Sensory neuropathy is the damage of the receptors or nerves. For people suffering with diabetes, the inability to regulate one's own blood sugar levels, loss of sensation occurs more in the long sensory nerves that provide sensation to the toes, and particularly the soles of their feet. Fingers tips and whole fingers can also be affected if the diabetic process is not controlled.

A similar loss of sensation to toes and fingers can also be caused by certain drugs used for cancer chemotherapy.

Vascular diseases are a group of conditions which affect blood flow, like high blood pressure and atherosclerosis. The limited blood flow can also lead to nerve damage and a loss of sensation.

It is important to note that this impairment of sensory function is usually permanent in nature and sometimes can become progressively worse and people with impaired sensation affecting the soles of their feet will have great difficulty sensing a potentially slippery floor, leading to the possibility of slips or falls.

Designing for Touch

When designing, textures can be readily used to distinguish between the nature of different surfaces. For people who have a reduction in touch sensation to fingers and feet, consider the contrast in surface texture, as a way to help them detect objects and surfaces. Vibrations that are sensed by skin receptors can help alert people to signals and danger. A good example of being alerted by vibration would be the 'silent' modes built into mobile phones. Vibrations sensed when moving over textured surfaces can be used to alert people of possible danger. One example where vibration works better than sound and vision are the white lines that determine the edges of motorway lanes. These textured lines create vibrations when vehicle wheels drift over them, alerting the driver to the position of the vehicle on the road. Vibration sense is also used at traffic light crossings for people who have impairment of vision and hearing.

In product design the different textures and weights of products can be used to add perceived quality, like denser paper weight in packaging. Detailed consideration of the textural qualities can often set the product apart from its competitors, particularly when designing for older people and those with disability. You can 'feel' the difference of a good quality product!

Balance

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B. Ear Canal
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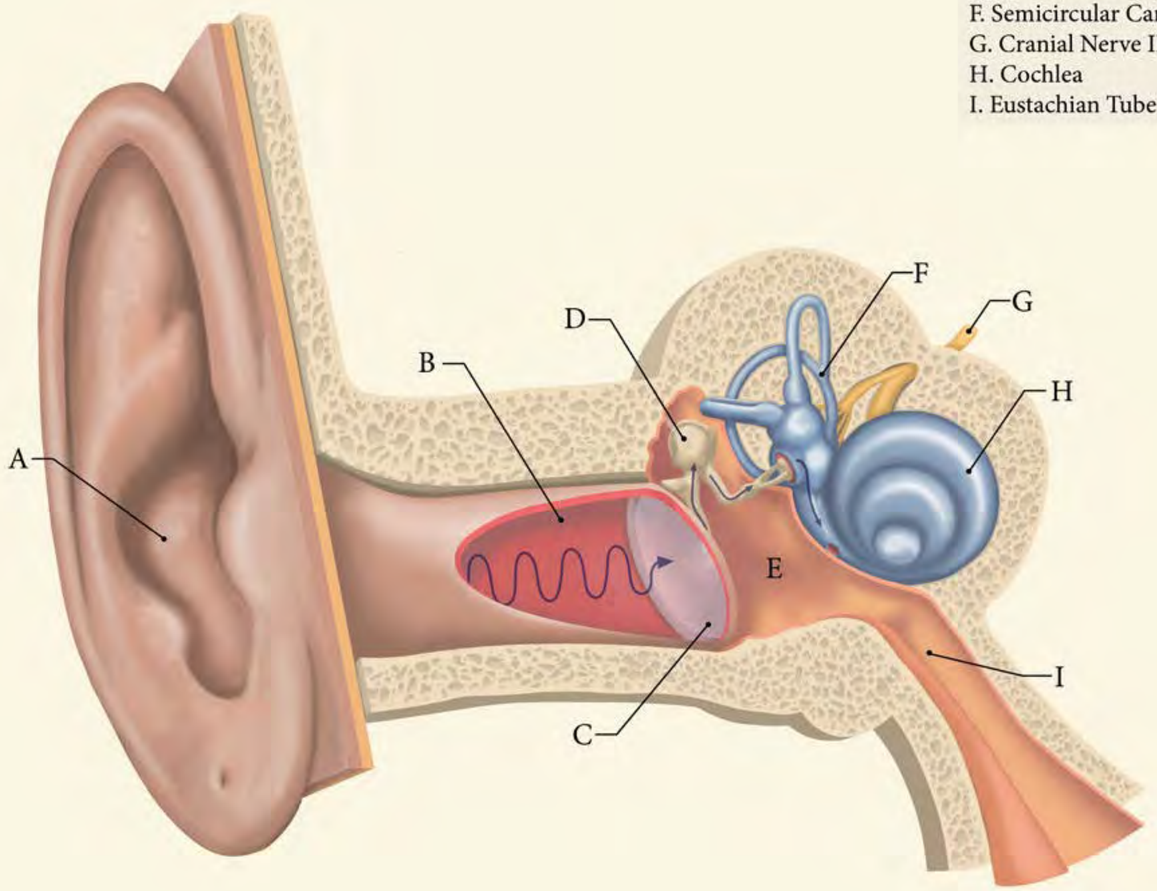
E. Tympanic Cavity
F. Semicircular Canals
G. Cranial Nerve IIX
H. Cochlea
I. Eustachian Tube



Balance is detected in the brain via several sensory sources. These include the vestibular system of semicircular canals, muscle and tendon position sensors (proprioception), sight and hearing. The vestibular system located in the inner ear with the cochlea.

Level Head Posture

Tilted Head Posture

Semicircular canals filled with fluid are arranged in three perpendicular directions and are lined with tiny hairs. These hairs detect the fluid's movement within the semicircular canals when the head is rotated and send these signals via the vestibular nerve to the brain. They are designed to orientate us in relation to gravity and position, and constantly help us to remain orientated in three-dimensional space.

Common Disabilities

Balance can be affected by a range of factors, common causes of longer-term poor balance relate to ageing and the side effects caused by some medications. Common causes of short-term balance impairment are intoxication with alcohol or drugs, head injuries and sudden inner ear viral infections.

Designing for Balance

Designing for loss of balance involves many environmental factors, from visual design like making rails and stairs more obvious with contrasting colour, to architectural design for slopes instead of stairs and well-lit environments. Consideration should be given to older people who often have impaired balance and restricted movement due to joint and muscular immobility.

Technology

An exciting new age of human/digital interaction now introduces the concept of a novel ‘7th sense’, the mobile device. These devices are in our hands, tucked in pockets or within hearing range and provide us with a wide range of new sensory interactions. The obvious sensory interactions are those of hearing and vision, but touch, vibration, 3-D spatial orientation also help us sense, perceive and navigate our complex world, both day and night. Smell and taste functionality is still at an early stage of development but watch this space! As mobile devices get smaller in size and advance in technology, there is the very real possibility if integrating them as part of our anatomy. A good example of integrated digital sensory devices that have been used for a number of years are Cochlear implants. These hearing devices are surgically placed in the temporal bone and cochlea, under the cover of normal skin and allow profoundly deaf people to sense and perceive sound.

Useful Links

Check the accessibility of your colour schemes
Adobe Colour: https://color.adobe.com/create/color-wheel

Do’s and Don’ts of Designing for disability
GovUK: https://accessibility.blog.gov.uk/2016/09/02/dos-and-donts-on-designing-for-accessibility/

Rod Mountains talk on Dundee design agenda
Pecha Kutcha Night Vol 11: https://vimeo.com/124414914

Design for disability talks
TED: https://www.ted.com/playlists/372/designing_for_disability

Designing for Touch
UX Matters: https://www.uxmatters.com/mt/archives/2020/02/designing-for-touch.php

Tactile surfaces
Arch Daily: https://www.archdaily.com/952355/why-we-should-integrate-tactile-surfaces-into-architecture

Classroom for the Blind
Arch Daily: https://www.archdaily.com/918942/classroom-makeover-for-the-blind-creative-crews

Health Building Notes
NHS: https://www.england.nhs.uk/estates/health-building-notes/

Examples of Healthcare design:
The Medical Futurist: https://medicalfuturist.com/finest-examples-brilliant-healthcare-design/

Future of Hospital Design
The medical Futurist: https://medicalfuturist.com/the-future-of-hospital-design-inside-the-point-of-care/

Biophilic Design
Building Design Construction Network: https://www.bdcnetwork.com/blog/biophilic-design-what-it-why-it-matters-and-how-do-we-use-it

Design Double Diamond
Design Council: https://www.designcouncil.org.uk/our-work/news-opinion/double-diamond-universally-accepted-depiction-design-process/