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Sensory Substitution for Visual Impairments: A Technological Review

Md Masum Billah, Zulkhairi Mohd Yusof, Kushsairy Kadir and Abdul Malik Mohd Ali

Abstract

This work shows the study of the people who are deprived of a sensory modality that affects brain organization and cognition. By studying, the blind or visual impaired helps learn about how sensory experience in each sense is required for specific brain systems to develop, and how the technologies help in plasticity change in their absence. The sensory-motor deprivation model serves to assess the roles of critical developmental periods, compensatory cross-modal plasticity, and sensory-independent (a-modal) processes in the human brain. Sensory substitution enables a new era for blind people. Therefore, this research will commit a complete review on the sensory substitution for visual impairments.

Keywords: blindness, visual technology, impairments, technology, eye-sight

1. Introduction

Visual weaknesses and visual impairment are practically basic wonders for the individuals who truly need help from others to navigate starting with one spot then onto the next. This gathering of individuals is denied of their ordinary life because of their visual issues. Despite the fact that a great deal of looks into have been done and some are proceeding for the improvement of assistive frameworks for this gathering which is totally unusable that can be acknowledged when practically 98% of visually impaired and outwardly debilitated individuals are totally relying upon the white stick as it were. Be that as it may, some are for the most part observed with the pooches in western nations for outside development, however despite everything it thinks about some peril while crossing the street and finding the method for course. Lab-scale models and couple of items for blinds are not finished enough for the visually impaired without the white stick or the help from others, so blinds cannot move alone while the advances are accessible. In this manner, another innovation which can be known as a tangible substitution as opposed to utilizing the assistive framework may assist the visually impaired individuals with moving alone with no other help.

2. Damage of visual sensory

2.1 Methods for recovery

Reclamation of tangible contribution in outwardly debilitated utilizing photographic inserts seems, by all accounts, to be an alluring option in contrast to tactile substitution gadgets, as they give a feeling of “genuine” vision, visual qualia (when contrasted with giving just visual data of vision). Gadgets dependent on different methodologies was demonstrated few encouraging outcomes, the visually impaired clients can, somewhat, use visual phosphenes produced by a portion of these gadgets to encounter important visual percepts. Be that as it may, in spite of the fact that they are at the forefront of medicinal, mechanical and logical advances, there are as yet a few noteworthy issues as of now keeping these methodologies from ending up evident clinical arrangements. As a matter of first importance, their intrusive nature makes them inclined to dangers identified with surgeries, for example, aggravation, drain, and expanded to deadness. Additionally, retinal prostheses are not material for populaces to visually impaired, as they require the presence of leftover practical retinal ganglion cells and visual tracts, while different visual impairment etiologies bring about their damage or nonattendance. Furthermore, these strategies are costly: the single sort of retinal embed which has as of late obtained in 2013 the principal FDA endorsement for constant implantation, Second Sight’s Argus II, which is currently the main business visual embed, is accessible at a costly expenses.

Subsequently, the sight substitution (currently ending up economically accessible past starter clinical preliminaries) do not yet give locate that looks like characteristic achievement specifically creating a really valuable and utilitarian vision, at moderate expenses still cannot seem to become to ideally end up accessible later on and empower the treatment of more extensive etiologies.

2.2 Gadgets for visual sensory replacement

The elective way to deal with sight replacement to the visually impaired is tangible exchange. Tactile replacement alludes change qualities tangible methodology upgrades other methodology. It is conceivable to supplant vision by contact or tryout, tryout or vestibular faculties by contact, and so forth. On account of visual deficiency, SSDs speak to a non-intrusive recovery approach in which visual data is caught by an outer gadget, for example, a camcorder and conveyed to the visually impaired by means of a human-machine interface as sound-related or material information. Braille was developed for composing spearheaded made ready to present day using speck code. Be that as it may, Braille can work for material changed disconnected from printed visual letters to Braille specks and cannot be utilized for internet perusing of customary letters. As of late other perusing substitutions have been created for internet perusing, for example, the Optacon (a print-totactual-picture gadget concocted for perusing emblazoned in different variants of committed content to-discourse motors. Notwithstanding these perusing helps, a lot of exertion has been put resources into creating gadgets planned for improving the portability of the visually impaired. The white stick used to precisely test for hindrances speaks to the least complex, most normally utilized gadget. Both the Braille framework and the stick arrangements, which were immediately adjusted by visually impaired clients, propose that now and again the easiest arrangement may be the one that is the most broadly utilized. Be that as it may, as of late further developed partners of the stick have turned out to be accessible, for example, electronic travel helps intended to be utilized alongside the white stick so as to

broaden the separation for ecological review and subsequently increment speed and proficiency of movement.

As opposed to these gadgets which are commonly intended for a restricted reason and are fruitful in supplanting just certain practical parts of vision, increasingly advanced procedures that supplant vision through material or sound-related data have been created in the course of the most recent couple of decades. The first focused on methodology to replacement of eye sight, because of the effortless and simplicity of changing visual into material sign which are both portrayed by two axes portrayals as shown in **Figure 1** [1].

Albeit amazingly extraordinary, both sound-related and material SSDs can conceivably be helpful for the visually impaired (however observe insights concerning their impediments in the following area; primarily the requirement for unequivocal preparing, the potential intrusion of sound-related sources of info and the low transient goals) [2–5]. Late tests demonstrate that blindfolded located people, and sometimes even the visually impaired can figure out how to translate the transmitted data and use it in a few basic visual undertakings, particularly in the wake of preparing or delayed utilization of the gadget [6].

2.3 Challenges in sight restoration

Current sight rebuilding endeavors, regardless of whether through intrusive or non-obtrusive strategies, still face a few difficulties to be appropriate to the general outwardly impeded populace.

These might be isolated to two primary highlights:

- Passing on data with adequate handy visual goals, or sharpness.
- Empowering visual useful handling of consistently complex scenes and undertakings
- Despite the fact that the two may appear to be to some degree compatible, they originate from altogether places.

Besides, at present the most progressive adaptation of visual inserts, retinal prostheses, are actually constrained to giving a restricted field of view because of issues in making inward embeds to fit the anatomical structure of the retina [7].



Figure 1.
Gadget for future sensory substitution [1].



Figure 2.
Eye sight complication.

Maybe additional significantly, subsequent sharpness become less compare to anticipated given the number of pixels, on grounds that the interpretation from specialized goals to utilitarian keenness is exceptionally perplexing as shown in **Figure 2**.

The issue of recommended usage of gadget is portrayed outcomes. The gadget gives from the earlier the most noteworthy hypothetical goals, hence a main possibility for visual restoration. Its principle detriments lie in the multifaceted nature of the generally low fleeting goals. In spite of the fact that the SSD change standards are moderately basic, deciphering pictures requires unequivocal and very broad preparing, which was not in presence at the beginning of my exploration. As a major aspect of the examination venture, I built up a focused on preparing convention in “figuring out how to see” utilizing the system. The subsequent issue, which will be nitty gritty in the following segment, has to do with cerebrum association, pliancy and neurorehabilitation, which is increasingly mind boggling, and relates to our comprehension of mind work [8, 9].

3. Visual rehabilitation features

Although additional creating to recovery procedures is as yet a huge innovative test, tactile rebuilding endeavors just transmitting the sight data, whichever by means of different by providing vision through the characteristic visual framework to the mind. As it were, when initially acquainted with the cerebrum of an inherently visually impaired individual, the visual data is futile on the grounds that that individual does not have any past involvement on which such data can be deciphered. Besides, the mind of such people may do not have a working visual framework for translating the recently presented data and giving it useful significance. Indeed, even on account of non-innately daze who have had some past visual experience, one cannot expect that re-acquainting visual data with their minds will naturally result in completely refined visual observation, since their “visual” cerebrum areas may now be incorporated into other, non-visual cerebrum systems [10]. This exercise rises up out of the moderately fruitful restoration of hard of hearing and auditorily weakened people utilizing cochlear inserts, which additionally requires express educating for individuals to figure out how to create new relationship among sounds and their sources. Besides, such recovery is joined and empowered by relating versatility in the sound-related cortex to react to the recently conveyed information. **Figure 3** shows the clinical visual rehabilitation process generally practiced in the rehabilitation center.

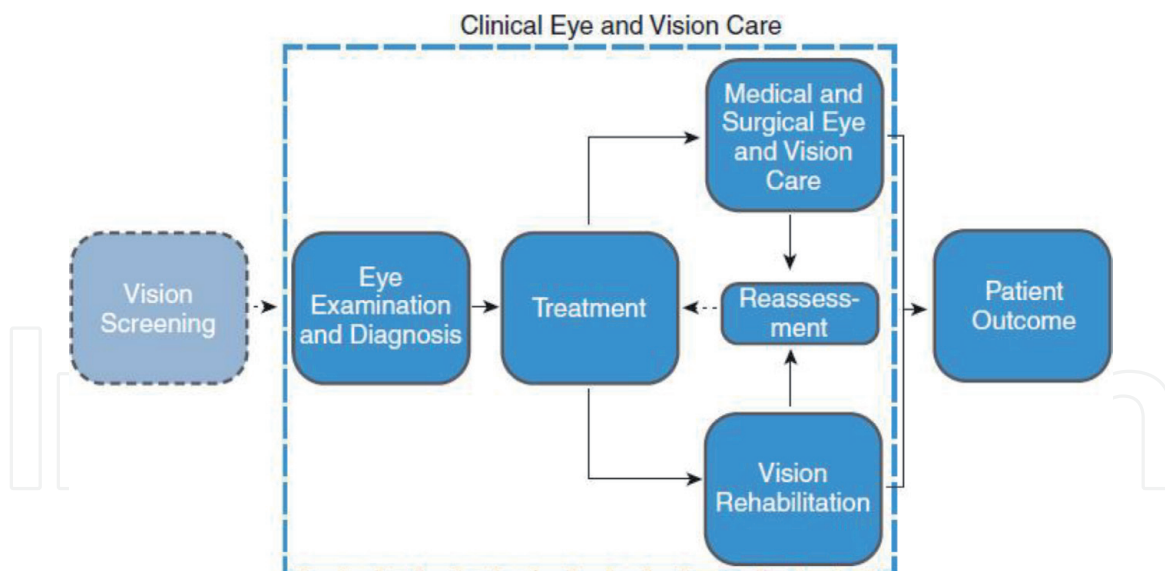


Figure 3.
Clinical visual rehabilitation process.

In reality, a few early endeavors at careful sight reclamation for visual information may likewise not get the job done if there should be an occurrence of vision [11–13]. The patients in these investigations indicated significant trouble in perceiving common articles and conditions, even after an extensive stretch of viewing preparing. This was particularly valid for ‘ventral stream capacities’, for example, shape and structure acknowledgment, figure ground isolation, profundity, size, and so forth. These visual disabilities remained so intense that in some announced cases the in fact “outwardly reestablished” individual retreated to living in useful self-characterized visual deficiency with no capacity to use the visual information now accessible to them. This is genuine notwithstanding for individuals who have lost their sight at more seasoned ages: an ongoing late-beginning visually impaired sight reclamation quiet whose sight was lost at 17 years old and reestablished 51 years after the fact additionally indicated real shortfalls in visual discernment. This demonstrates enabling the visual data to enter the mind through a practical retina does not ensure or empower full or characteristic visual discernment. Subsequently, accomplishing full useful tactile rebuilding might be conceivable on the off chance that we consider the specificities of intellectual and neural working of the tangible disabled, a subject which will be exhibited straightaway [14].

3.1 Damage significances

Once endeavoring for comprehend psyches and cerebrums of people damage a tangible methodology, an imperative take data of the numerous variables that influence the association cognitively. These are joined from our hereditary auras and the cerebrum’s common formative way, diverted relying upon natural variables and explicit individual encounters and exercises, and through progressively novel psychological difficulties and requests forced by nonstandard tangible sources of info. In particular, so as to accomplish the equivalent useful level in their regular daily existence, the individuals who experience the ill effects of tactile misfortune need to create procedures which empower them to extricate data to accomplish their objectives from elective sources to make up for their visual impairment. Such alterations are intervened through rebuilding in other tactile or higher-request psychological capacities (for instance over the top utilization of memory systems, see subtleties underneath). Accordingly, unique psychological requests lead to various

individual encounters and exercises, which thusly advance a specific example of plastic rearrangement inside the sensory system.

Moreover, it is imperative to remember that different subpopulations of people experiencing visual misfortune and varying in etiology or beginning of tangible misfortune contrast in their potential for versatility. The early beginning of tangible misfortune experienced in inborn visual impairment triggers the most sensational instances of versatility and empowers broad mind rebuilding which makes up for the shortfalls, producing a strikingly unexpected useful system in comparison to the one seen in ordinarily located people or people who have supported cerebrum or fringe wounds sometime down the road. Inborn or early-beginning visual deficiency influences huge bits of the mind, particularly when coming about because of fringe harm (for example broken retina or the tactile tracts), which do not harm the mind itself, however rather retain portions of the cerebrum from their common information, leaving it basically jobless. The visually impaired do not deteriorate. Or maybe, they experience broad versatility coming about in altogether changed neural responsiveness just as utilitarian contribution in non-visual psychological capacities. Critical, albeit normally less broad plastic changes, likewise happen in populaces experiencing non-inherent tactile misfortune. The neuroplasticity is clear normal mind actuation in the visually impaired when contrasted and that of the located, just as in its social appearances, e.g., tactile explicit psychological aptitudes, which are all essential to the capacity to reestablish locate sometime down the road.

The main proof for the broad rearrangement experienced by the cerebrums of the inherently visually impaired can be found in the revealed upgraded tangible and psychological capacities of such people which make up for their tactile shortages. Daze people need to make up for their absence of vision, the methodology which ordinarily enables one to “comprehend what is the place by looking and is perfect for giving simultaneous data to one another, attracting consideration regarding pertinent outside signs and incredibly encouraging spatial coding. In spite of the fact that the visually impaired cannot secure data for item limitation and acknowledgment by looking, despite everything they need this data to explore to find and perceive the articles around them for instance. Accordingly, they need to get this data through option, tangible or other, methodologies. For example, as right on time as the age of the Mishnah that was realized that visually impaired people had better memory capacities looked at. Thus, it has been demonstrated that the visually impaired have predominant material and sound-related discernment capacities: for example, they can all the more likely separate between little material dabs or sound-related spatial areas than the located, and even to more readily distinguish smells. In any case, the visually impaired do not generally perform better on such undertakings, proposing that ideal advancement of certain parts of tactile handling in the unaffected modalities may rely upon, or possibly advantage from, simultaneous visual info. Moreover, when looking at changed populaces of the visually impaired, it turns out to be evident that the recognized advantages in some sound-related and material undertakings depend, as it were, on the age at sight misfortune [15].

In particular, these points of interest are frequently, yet not constantly, constrained to the innately and early-beginning visually impaired, though the exhibition of the late blinded will in general take after that of the located, reflecting contrasts in the measurement of visual experience between these populaces. Notwithstanding, there is likewise proof showing that compensatory benefits additionally happen in the late visually impaired, in which case they might be interceded by various neurophysiological components as point by point in the following areas. Critically, albeit delayed involvement with a diminished number of accessible tactile modalities prompts such advantages, these do not show up naturally. For instance, it has been demonstrated that visually impaired youngsters have huge troubles with certain assignments,

particularly those which expect reference to outside signals, getting bearings and spatial relations between items. Such undertakings are trying for the visually impaired, as they have bargained spatial portrayals and depend for the most part on self-reference and development groupings. Therefore, the visually impaired have issues perceiving possibly valuable data expected to play out these sorts of assignments and do not have the advantages which could emerge from all the while accessible vision. For instance, simultaneous visual info can encourage acknowledgment and learning of accommodating sound-related or somatosensory highlights given that the presence of excess or covering data from more than one methodology is by and large connected with controlling consideration and improved learning [16]. In any case, such acknowledgment of valuable signals or the alignment of sound-related and material space is in the end conceivable even without vision, as it might be accomplished utilizing various prompts, for instance those originating from self-movement. Significantly, despite the fact that it might require moderately extensive preparing to arrive at a phase where the missing tangible information is swapped and made up for by comparable data from different modalities, spatial portrayals which are at long last created based on haptic and sound-related contribution of the visually impaired appear to be equal to the outwardly based ones in the located. Generally speaking, the discoveries demonstrate that the visually impaired, when they figure out how to manage the accessible tangible modalities, can indicate equivalent or unrivaled execution in numerous errands when contrasted with the located. This preferred position can even be undermined by the nearness of visual data, as demonstrated by second rate execution of the somewhat visually impaired. In this manner, the accessible proof will in general counter the thought that tangible misfortune prompts general maladjustment and brokenness in capacities outside the missing methodology. An incredible opposite, this general-misfortune theory ought to be relinquished for the option, compensatory speculation which recommends that tactile misfortune prompts the unrivaled improvement of the rest of the faculties [17].

These interesting compensatory capacities are the aftereffect of plastic changes in the cerebrums of the visually impaired. Over the most recent couple of decades, neural connects of revealed weakness actuated changes in psychological capacities and procedures have been altogether contemplated, giving an abundance of data with respect to the cerebrum's capacities to change. Studies researching neural handling of innately dazzle people, just as creature models of these conditions, demonstrate that the cerebrum is equipped for vigorous versatility reflected in significantly adjusted working of whole mind systems. Significant proof relating to the modified intellectual handling and the practical status of the occipital cortex in the visually impaired stems from electrophysiological contemplations which have researched non-visual tangible elements of the visually impaired. These yielded outcomes demonstrating shorter latencies for occasion related possibilities (ERP) in sound-related and somatosensory assignments in the visually impaired as opposed to the located, proposing increasingly effective handling in these undertakings. In the visually impaired, huge numbers of these progressions begin to happen inside days following the beginning of visual impairment and in this manner influence the intrinsically visually impaired as well as the late visually impaired, who likewise show critical revamping in the occipital cortex in spite of the fact that to a lesser degree. For instance, late-beginning visually impaired individuals show enactment in their essential visual cortex for language recognition.

This versatility, particularly in the early-beginning visually impaired, may go about as a twofold edged sword. From one viewpoint, it enables the visually impaired adapt to better to visual impairment by supporting compensatory capacities, and yet it may meddle with sight rebuilding endeavors by exasperating the first elements of the visual cortex, as will be itemized in the following segment.

3.2 Developmental periods of sensory loss

When talking about various kinds of neuroplastic changes and potential instruments fundamental them, and the unfavorable consequences for the regularly creating visual framework with regards to visual restoration, underline that these shift altogether rely upon the age at beginning of visual deficiency, just as its span. These distinctions mirror a few factors: the cerebrum's capability to change at various times of advancement, the measure of involvement with visual or sound-related preparing preceding tangible misfortune and the measure of training with the rest of the faculties or some unique material. The most significant of these components mirrors the way that the general potential for any type of plastic changes differs gigantically over the life expectancy. In spite of the fact that the cerebrum holds some capacity to change all through life, it is by and large accepted and tentatively supported that the sensory system is most plastic during its advancement, both on account of ordinary improvement and following mind damage [18]. The creating cerebrum is an exceedingly unique framework which experiences a few unmistakable stages from cell development to the fast development and ensuing end of un-utilized neural connections before at long last going into an increasingly steady stage following adolescence. The utilitarian task of individual cerebrum locales which happens during this time is vitally reliant on synaptic improvement which incorporates extreme changes that frequently occur in spurts. In the visual cortex, during the primary year after birth, the quantity of neurotransmitters develops hugely and is accordingly downsized to the grown-up level around the age of 11 through broad abatements in synaptic and spine thickness, dendritic length or even the quantity of neurons. This procedure is basically controlled by understanding and neural action: neurotransmitters which are utilized are fortified while those which are not strengthened or effectively utilized are killed. Synaptic improvement is exceptionally subject to rivalry between approaching data sources, the absence of which can bring about a diminished degree of synaptic correction and perseverance of repetitive associations in adulthood. This procedure of synaptic pruning speaks to a genuinely ceaseless and expanded tuning of neural circuits and can be diverged from different sorts of changes which happen at exceptionally short timescales. During such times of strengthened and improvement of sensory loss, a huge operational procedure was required for recovery. Along these lines, wounds influencing various phases of advancement, notwithstanding when they happen at a generally comparable ages, may trigger unmistakable examples of compensatory neuroplastic changes and lead to various degrees of recuperation. In particular, early investigations of recuperation after visual misfortune in creature recommended that vision is especially delicate to getting regular contribution during early advancement, and that visual hardship notwithstanding for brief terms, yet at an early formative beginning, may irreversibly harm the capacity to typically see vision at more seasoned ages. Instances of waterfall evacuation in outwardly disabled youngsters bolster these discoveries. For instance, youngsters brought into the world with thick respective waterfalls and afterward treated during the primary year of life later by and large create typical vision, and are not debilitated at either low level visual capacities and abnormal state capacities. Since these abilities surpass those present during childbirth in the outwardly ordinary youngster, the typical presentation of waterfall inversion patients likely suggests that the neural circuits fundamental these capacities can recoup totally from a brief time of prior visual hardship. In any case, if the waterfalls are not expelled early enough, the waterfall inversion patients may later experience the ill effects of decreased visual keenness and hindrances abnormal state capacities, for example, diminished visual gathering capacities and hindered face preparing doubt even after early youth, visual data is significant for

the crystallization of visual associations long after the finish of pruning, however the deficiencies created from short visual hardship starting at early immaturity for instance are progressively moderate [16–18].

In this way, visual hardship, particularly if showing from the get-go throughout everyday life, can devastatingly affect the capacity to process vision. Additionally, the capacity of the cerebrum to adjust, or the potential for neuroplasticity after adolescence is viewed as much lower than in youth. Moreover, the pliancy found in adulthood will in general outcome from various neurophysiological systems, which may not get the job done to help visual recovery. For instance, the vigorous, transient pliancy saw in blindfolding for a few days may emerge from the enlistment of officially existing, however ordinarily unused, hindered or conceal pathways which become accessible once the source or explanation behind such covering is evacuated. Along these lines, a few types of grown-up pliancy do not reflect that portrayed by the production of new availability designs. In neurotic states, wounds, or late tangible misfortune, versatility might be blended. Fast changes mirroring the exposing of existing associations happening in the primary stage advance and may empower resulting moderate, yet increasingly perpetual basic changes.

3.3 Visual cortex in the brain

Another factor worth considering in this regard is the huge intricacy of the visual preparing led in the cerebrum, and its imperative fundamental neural structures. The regularly created visual framework is a complex neural engineering of parallel and interweaved handling, with a perplexing division-of-work in which various areas have practical experience in the preparing of various visual highlights, errands and even articles. For instance, the visual cortex is included two handling streams. The ventral occipital-fleeting pathway has been connected with visual handling of structure, object character and shading. Its partner is viewed as the dorsal occipital-parietal “where/how” pathway, or the “dorsal stream”, which examines visuo-spatial data about article area and takes an interest in visuo-engine arranging and outwardly guided development. It has been more than once demonstrated that in typically located individuals who have endured a sore in one of these alleged neural modules or notwithstanding preparing streams, the impression of items handled in this district might be seriously impeded [19]. For instance, the twofold separation between the preparing of the two streams has been altogether approved by investigations of confined sores independently influencing visual item personality acknowledgment (visual agnosia) and article visuo-engine spatial control, and an injury or deafferentation of the VWFA may bring about alexia, or procured dyslexia.

The anatomical reason for this division has additionally been contemplated, and shows a mind boggling example of base up availability, starting with the essential visual cortex and making two parallel (however not totally free) anatomical network streams, one of which leads dorsally, through the back parietal cortex towards the premotor cortex, accordingly making a characteristic “way” towards arrangement for movement and spatial handling, while different leads through zone V4, which is specific for the shading and size of visual, to inferotemporal territories containing complex visual article portrayals, and up to the prefrontal cortex. Thus, the various leveled handling of the low-level highlights of the states of letters, their further sequencing to words and after that to progressively extract semantic portrayals additionally shows in an anatomical preparing pathway. This hard-wired bottom up availability example makes a solid limitation towards the age of these streams and districts within the sight of typical visual contribution during improvement. In any case, the production of two separate visual streams, or that of independent area specific locales inside the streams, and their utilitarian selectivity

may not be so trifling without visual info, which denies the visual cortex of its regular information, particularly given the distinctive powerlessness to versatility over the life expectancy. Since these streams and locales have been demonstrated to be basic for the best possible preparing of item shapes, areas just as better evaluation highlights, for example, content (as confirm by the previously mentioned injury contemplates), it is conceivable to ask whether visual acknowledgment can happen at all without building up the full degree of the complex visual cortex design.

Every one of the components nitty gritty so far show the requesting provokes that still should be handled by sight rebuilding endeavors. In the event that the visually impaired cerebrum has experienced broad changes, and the inherently visually impaired mind might be considerably more definitely modified since it did not get the visual data sources guiding its ordinary advancement in the first place, how might we anticipate that the visually impaired should figure out how to see vision?

4. Auditory sensory substitution

Sound-related SSDs can offer, in any event hypothetically, incredibly high goals. While one such gadget utilized in research and with an end goal to restore the visually impaired has a maximal hypothetical goal of just 124 pixels can on a fundamental level create a lot higher goals, up to 25,344 pixels. Nonetheless, its real practical visual sharpness has never been tried as far as we could possibly know, and particularly not in a visually impaired clients bunch methodically. It is consequently critical to decide the most ideal visual sharpness that can be accomplished by visually impaired people utilizing such a sound-related SSD, so as to comprehend the potential estimation of these gadgets [20, 21]. Besides, as basic formative periods for view of common for confinement the medicinal methods for sight rebuilding (for instance, a few uncommon records of sight reclamation in adulthood brought about just incompletely useful vision, likely because of such restrictions; it is fascinating to decide whether early-beginning and intrinsically dazzle grown-ups can figure out how to see fine “visual” subtleties after numerous long stretches of visual deficiency utilizing SSDs.

4.1 Sounds: sensory substitution

A few investigations have indicated enlistment of visually impaired for different assignments that copy the visual errands of similar districts in the located. This

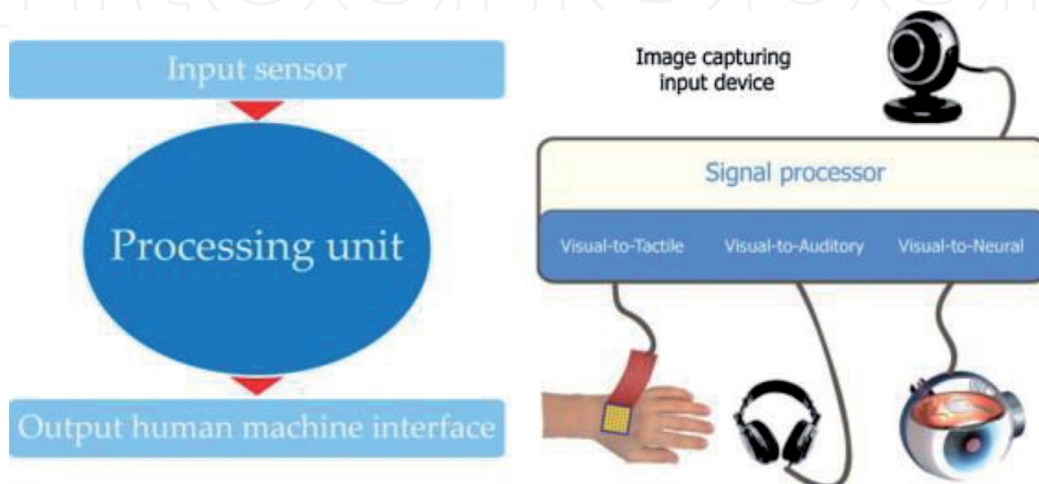


Figure 4.
Auditory sensory substitution concepts.

incorporates enlistment of the material improvements through a perusing task. Notwithstanding, few examinations have indicated selectivity to one errand over another and less yet have researched the presence in the visually impaired of a basic component of the ventral visual cortex, to be specific, its local selectivity for perceptual classes that despite the fact that our SSD change rations the state of the letters, it is impossible that a particular low-level tangible shape handling emulating vision drives the initiation or selectivity saw in our outcomes, since the physical measurements on which it is based contrast incredibly from those portraying both visual and material as shown in **Figure 4**. In particular, visual highlights that have been proposed to drive the selectivity for letters, for example, high-recurrence vision.

5. Conclusion

This work shows the study of the people who's are deprived of a sensory modality that affects brain organization and cognition. By studying, the blind or visual impaired helps learn about how sensory experience in each sense is required for specific brain systems to develop, and how the technologies help in plasticity change in their absence. The sensory-motor deprivation model serves to assess the roles of critical developmental periods, compensatory cross-modal plasticity and sensory-independent (a-modal) processes in the human brain. Therefore, this research will commit a complete review on the sensory substitution for visual impairments.

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Conflict of interest

The authors declare no conflict of interest.

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keratoplasty with and without
intraoperative suture adjustment.
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