A Comprehensive study on Brain Mechanisms for Language Acquisition and Comprehension

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Abstract

This study intends to bring the main viewpoint of language acquisition and language comprehension. We have reviewed the different types of language acquisitions like first, second, sign, and skill. The experimental techniques for neurolinguistic acquisition detection are discussed. The findings of experiments for language acquisition are analysed, which involves the brain region activated after the acquisition. It demonstrates the different types of language acquisition involve other areas of the brain. In language comprehension, native language comprehension and bilingual's comprehension have been considered. Comprehension involves different brain regions for a different sentence or word comprehension, depending upon their semantic and syntax. This review has also addressed the other fMRI /EEG analysis techniques (statistical/ graph theoretical). Neurolinguistic computational tools (pre-processing/computations/analysis) and varied computational techniques for neuro data are also explained.

Keywords: Language Acquisition, Language Comprehension, Cognition, GLM, ICA, PCA, ERP, fMRI, Machine Learning .

1 Introduction

The past few decades have yielded enormous research work in neuroscience investigating language acquisition, comprehension, and production. Nowadays, non-invasive and healthy brain function assessment is feasible for acquiring neural data of any age group of people (adults or infants). Broca and Wernicke regions of brain play an important role in language processing [1]. Native or First Language acquisition is an innate property of a human that a newborn starts acquiring by self. On the contrary, second language acquisition can be initiated at any age of life, [2]. A baby's early age is considered a critical time. During this tenure, the child should start First Language acquisition for better language command [3-4]. The acquisitions of language by the children are natural that gives the thought that the procedure of first language acquisition is direct and easy [6]. There are three popular first language acquisition theories Behaviourist, Innatist, and Interactionists theory [7-9]. In their life, humans acquire first, second, a sign language, or some skills [10].

The early age of acquisition of the first language in the child is associated with their reading capabilities [11-12]. An fMRI-based study shows evidence that the concentration in the brain's occipital cortex changes by the delayed first language acquisition in tissue. Delayed First language acquisition does not only affect the functional but anatomical structure of the brain also[28-29]. Any language skill acquired after the native language is the second language (L2). From various studies, it has been observed that the neural representation of the second language is different from the first language [31-32]. As the second language is acquired at a late age, it requires more neural resources in language processing [33]. The age at which a person learns a second language, mainly bilingual that affects the brain structure [37]. Deaf infants learn sign language at ages even beyond infancy. The language processing in the brain is affected by the variation in the age of sign language acquisition [44-45].

Generally, any skill is acquired after First Language acquisition. The beginning of the skill acquisition age is related to the neuroplasticity of the brain [49]. It has been observed that in the early age of life, the brain is in the most active phase of building. A clear relationship has been shown between skill acquisition, and skill performance is related to the optimal age [51]. It was recommended by the expansion-renormalization model thet during skill acquisition human brain structure changes[52-53, 105].

Sentence comprehension depends on noun phrases [55]. Left superior temporal sulcus, inferior frontal gyrus, and left basal ganglia regions of brain show a systematic enhancement in brain activity. During sentence processing, indicating their role in computation semantic and syntactic structures [56]. A sizable part of the world is bilingual and proficient in speaking more than one language—a bilingual use additional brain regions in language processing [65].

Due to the advancement of medical instruments, brain data acquisition is available in various formats, from images to electrical/magnetic signals. The most popular non-invasive imaging techniques are MRI, rsMRI, fMRI and DTI. Other non-invasive signal acquisition techniques are EEG, MEG, ERP, PET [79-92].

For examining different types of neuro data, several data analysis techniques are widely used. The popular data analysis methods are Statistical Analysis methods and the univariate/multivariate methods like GLM, ICA, PCA and SVM [93][95]. For analyzing and visualization of data, neuroimaging software tools like AFNI, CONN, EEGLAB, Free-surfer, and SPM are being employed [96][102].

In this article, section Language acquisition (Sec. 2) discussed the principle of language acquisition like first, second , sign language and skill acquisition, section Language comprehension (Sec. 3) discussed about language comprehension and bilingualism, section Data Acquisition and Analysis Techniques (Sec. 4) discussed different data acquisition and analysis technique and in final section conclusion (Sec. 5) draw the conclusion.

2 Language Acquisitions

The human brain commands central controls of heart rhythm, memory, and language to all human activities. Two main regions Broca's and Wernicke's area are responsible for language acquisition in the human brain. For coordination and language production, Broca's area is mainly accountable. It is a small region in the inferior frontal gyrus and is mostly found in the left hemisphere. In contrast, for written and spoken language comprehension Wernicke’s area is responsible. It is present in the superior temporal gyrus (STG) that is the counterpart of Broca’s area. Broca's area is generally consists of the Brodmann BA44 cytoarchitecturally specified region, the pars opercularis and BA 45 pars, and the triangularis pars. Whereas Wernicke's area usually has BA 22, i.e.

cytoarchitecturally identified region and contains the latter two-thirds of the STG's lateral convexity[1]. The whole-brain structure is responsible for language acquisitions, including Broca's and Wernicke's areas shown in Figure 1.

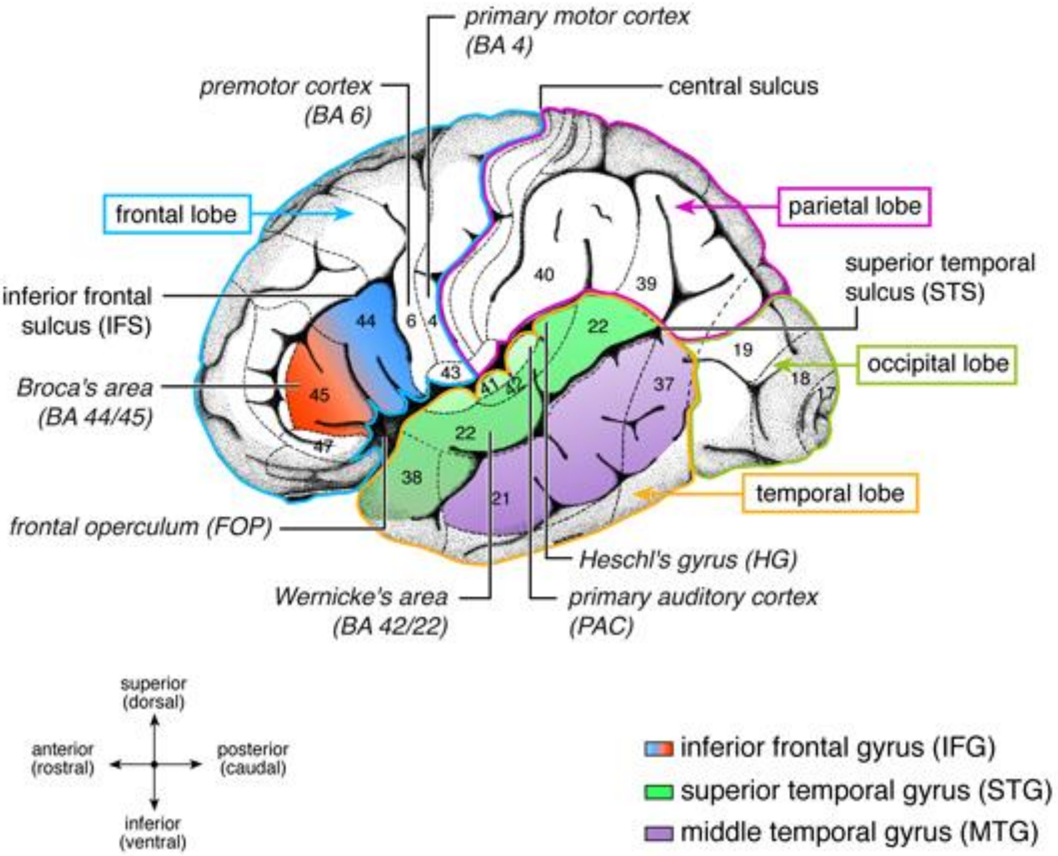

Figure 1: Language region of human brain comprises the regions of Broca and Wernicke (adapted from Friederici 2011[1])

The acquisition of languages is one among the most important essential human characteristics, and indeed, the brain undergoes evolutionary changes. Therefore the origin of the orthography should be an inherent mechanism with the human brain. Linguists find speaking, signing, and understanding language to be the decisive language skills, i.e., natural or inborn and biologically laid down. In contrast, they find writing and reading to be secondary. In truth, acquiring a native or first language ("L1") through these primary faculties during the first years of life, whereas children gradually learn their linguistic knowledge. The progress of acquiring speech capability in children can improve until the age of 2 years. At the age of 6-8 months, babies start babbling. At 10-12 months, infants start speaking using single words and then progress to the two-word stage at about two years. There is a profound difference between linguistic factors "L1" and "L2". An "L2" (Second Language) could be learned at any time in your life. However, the L2 capacity is scarcely comparable to that of L1 if it is acquired after the predicted sensitive period from early childhood to teenage years. Numerous studies of fMRI and PET have shown that auditory phonological processing is correlated with activation in the posterior STG [Brodmann's region (BA) 22]. In contrast, lexico-semantic processing including the angular ones is typically connected with activation in the left extra Sylvian temporoparietal regions [2].

In [3], Eric Lenneberg (1967) proposed that acquiring human language was a case in point of biologically limited learning. The author stated that a child would have a heritable biological component to learn a language. The process of acquiring a language is profoundly ingrained and, species-specific, human biological property. Any language is usually acquired during a critical time, beginning early in life and ending in puberty. Further, it is also discussed that learning the first language might be difficult beyond the critical time or may require different methodologies to learn any language.

Maturation is a critical period in which the development of the human brain or learning a new language would peak. As a result, the standard action adapted for the specific situations being exposed. If the human brain fails to adopt this phenomenon during the maturation process, the organism is not subjected to this phenomenon until after the critical period. The same phenomenon may have either a mediocre result or may not affect at all in extreme cases. Studies show a close association between language use age and the ultimate degree of competency (PL) attained. However, exposure to age does not affect all facets of language learning correspondingly. Therefore, the acute effects of the critical period seem to focus on phonology, morphology, syntax, and not meaning processing [4]. Language acquisition occurs during a critical or sensitive period in humans was explained by an evolutionary model suggested by J. R. Hurford in [5].

The first language acquisition is one of the unexplained vagueness that surrounds us in our day-to-day activities. A child learns language spontaneously, almost unbelievably, as its learning of language progresses rapidly with an apparent pace and accuracy. Most children quickly learn a language, giving the illusion that acquiring the first language is easy and straightforward. The study says that there is no evidence of such cases. However, children are going through many stages of first-language learning, such as cooing, babbling, holophrastic stage, usual telegraphic speech. The age of cooing is up to nine months, and children use phonemes as of every language. At nine months, they start babbling in which they selectively use phonemes from their inherent language. At the age of 12 months, they start using single words. When they are in the holophrastic stage at around 18-24 months, they try to join one word with other words. At the stage of development of about two and a half years, the telegraphic stage has been developed. At this stage, the baby can speak a clear structure of the phrase. As the children develop physically, so does their language skills as they co-opt a more complicated structure by widening their vocabulary and immediate surroundings. At the age of 5 years, children reached up to normal developed speech [6].

There are three famous theories for first language acquisition: the behaviourist theory, the innatist theory, and the interactionists theory. Behaviourist theory [7] equated learning to a language; all verbal behaviour is acquired through interaction with the environment, and interactions are imitation, reinforcement, practise, and habit formation.

Children learn their first language by stimuli, and their responses are influenced by reinforcement. According to the Innatist hypothesis [8,] children are born with UG (universal grammar) as well as a device called the LAD (language acquisition device).It is responsible for proficiency of language in children regardless of the extremely abstract character of the language. The Interactionists [9] believe that language is not an isolated element of the brain as language reflects the information gained through children's physical contact with the world. Based on the study of language acquisition in the brain, it is categorized into four categories. The categories of the language/skill acquisition process are shown in Figure 2.

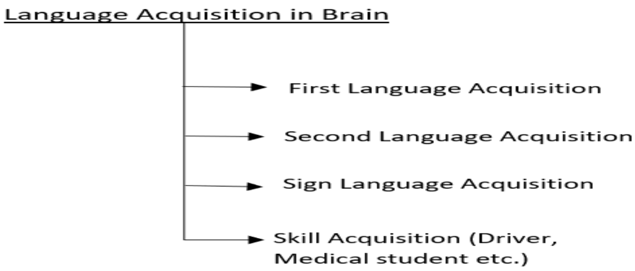

Figure 2: Language acquisition in human brain

The acquisition of language in the brain can be of four types: first language, second language, sign language, and some additional skills, which consist of some specialized/additional forms of language. The first language is the native language, which the infants acquire naturally in the social environment. Next, for second language acquisition, the prior experience in the first language substantiates to be an improvement to them as they have an idea about the language working principles. Second language learners often acquire cognitive maturity and knowledge of meta-linguistics that would be convenient for resolving the problems while talking in the second language [10]. Sign languages are used for communication inborn deaf people. The learning and acquisition of sign language start at later age, well beyond the infants. The brain acquires skills by some special training or by practice. For example, the driver learns how to drive; a medical student learns and acquires knowledge of respective specialization, and the interpreter learns new foreign languages.

2.1 First Language Acquisition

Acquiring language and reading/writing skills at the early stage of childhood has been related to subsequent reading performance and can affect academic achievement, mental health, and possible job opportunities [11], [12]. Neuroimaging studies help us to enlighten the interaction between brain and language skills in white matter architecture. Studies show that young children rely on a large brain network to process languages, which becomes a more focused network with an increase in age [13].

Functional Near-Infrared Imaging (fNIRS) studies [14] highlights that the learning of words and forming sentence structure in children. The mark syllable, slow rhythmic modulations in the linguistic stream (< 8 Hz) and word restrictions in the continuous linguistic stream helped a lot. Children's sensitivity toward slow rhythmic modulations inherent in the linguistic stream. It aids language acquisition in infancy and the transition from spoken to written language during the early years of reading acquisition [15-16].

Neuroimaging research indicates that after hearing the language, adult brain neural networks enter into a synchronized connection between the linguistic stream's various frequency modulations and the neural activity's endogenous rhythmic oscillations. Neuronal firing frequencies are recognized to oscillate at differing frequency bands, together with Delta (1-3 Hz), Theta (4-8 Hz), and Gamma (30-80 Hz). Slower syllabic frequencies plus word limits (Delta to Theta) and faster frequencies suit individual phonemes [17-18]. The results indicate that the right hemisphere may have an overall enhanced capacity to handle the rhythmic response. While the left hemisphere could have a selected response to a preferred set of sluggish rhythmic modulations. Which may be especially prominent for the brain system responsible for reading and cross-modal language processing [19].

Spatial language acquisition (SLA) consists of a frame of reference (FoR) [20], which individuals acquire in their language (left/right and north/south). Languages differ broadly based on the frequency and availability of FoR (frame of reference) terms. [21-24]. For illustration, some languages favour geocentric terms like “north” or “uphill”, while English have a preference for egocentric terms (“left”, “front”) for describing small-scale table-top arrays. Moreover, It is indicated by a number of studies that there is a link between the dominant FoR in a linguistic community and the availability of FoR representations in nonverbal cognitive tas ks among members of that community[25-26].

Authors in [27] experimented on children, and findings indicate the dependence on pre-existing language circuits to acquire new native-phonology word types. This explains how, after a few repetitions, the children learn new vocabulary.

Authors in [28] conducted an fMRI experiment. They stated that there is a co-relation between late learning of a first language and modifications in tissue attentiveness in the occipital cortex near the region. It helps in functional recruitment of language processing at late learning period. Such results indicate that the absence of familiarity with primary language affects both functional and anatomical brain organs [29].

Authors in [30] found that feedback had a significant impact on the structure of the network used by a person to learn the proficiency of words of natural language. A statistical learning framework suggests that learners perceive distributional information and use that knowledge to derive the structure and concepts received from the sensory inputs. For example, a newborn can segment words from an artificial language by analyzing the likelihood of transitional syllables in running speech.

2.2 Second Language Acquisition

The acquisition of their vocabulary is a crucial part of learning a new language. Morphology in the linguistic sense is the study of words, how they are created, and how they relate to other words in the same language. A study in [31] discussed the neural signature in the initial phase of morphological rule-based learning of a novel language (L2) in adults and suggested that an adult learner could learn novel words as well as L2 morphological rules at a very short experience.

Bilingualism studies have identified ways in which a second language’s neural representation (L2) varies from that of the first language (L1) of a person [32]. Particularly, In terms of degree and extent there are many distinctions between L2 and L1 in case of activation. L2 tend to display not only additional activity within the region of the traditional language of the left hemisphere but to enable more regions beyond the traditional language network also. There are two prevailing hypotheses about why L2 neural signatures vary from L1 signatures. The first is that, during L2 learning, these variations reflect decreased neuroplasticity that happens at a later age of life than learning with first language. As a result ,L2 learning requires increased neural resources.This happens due to maturational changes in neural plasticity within the areas and pathways that facilitate first language acquisition [33]. The theory is that neural distinctions between L1 and L2 are caused by the fact that people's L2 is generally less proficient than their L1. Therefore, the processing of L2 requires increased computational requirements and thus increased neural resources [34]. The experimental results highlight the ability and AoA to describe different structural and functional networks within the bilingual brain, which is interpreted by us as an age-dependent effect of distinct types of plasticity vs competencies and/or experience.

Authors in [35] consider structural changes to brain areas believed to support language roles during learning a foreign language. Experimental findings show that the cortical thickness of the inferior frontal gyrus and the volume of the hippocampus, superior temporal gyrus and left middle frontal gyrus increases for interpreters compared to controls. In interpreters with higher foreign language abilities, the right hippocampus and the left superior temporal gyrus were anatomically more flexible[36].

A study in [37] investigated how the age of L2 acquisition impacted brain structures in bilingual people. This shows that AoA, language skills, and current exposure rates are equally crucial in taking into account the systemic differences. Anatomical changes related to multilingualism and bilingualism are also identified. Bilinguals appear to increase the volume/density of grey matter in the Heschl's gyrus [38], the left caudate [39] and the left inferior parietal structure [40].

The authors of [41] analyzed the relationship between skill in instructed second language acquisitio n (ISLA) and attitude toward language learning, and discovered a strong connection. The analysis of language learning achievements in monozygotic and dizygotic twins [42] points to the possibility that it is having a positive attitude towards language class and learning. It also highlights that how a student behaves independently in ISLA from teacher skill and L1-L2 learning.

In [43] a group of healthy adults the authors examined the neural substrate of learning novel grammar. The experiment has been conducted on fMRI data and finds the functional connectivity and brain network involvement at grammar acquisition. The experiment finds the language learning ability and states that grammar learning and language learning ability are highly correlated.

2.3 Sign Language Acquisition

Children by birth deaf cannot understand the languages uttered around them, and there is inadequate phonetic information provided by the visual signal of speech to facilitate impulsive language acquisition.
After being exposed to and immersed in sign language at a young age, many of these children's lang uage learning continues even beyond infancy. Deviation in the period of language acquisition in the adult brain, influences language processing[44-45]. fMRI experiments of deaf native signers have found activation in the classical language areas of the left hemisphere LH with a trend towards temporal and frontal lobes activation. These findings were observed using different tasks and triggers for distinct sign language viz. British, Japanese, and American [46-48].

In anterior language regions, Age of acquisition is linearly and inversely related to activation levels. It is positively related to activation rates in subsequent visual regions for linguistic tasks of phonemic hand judgment American Sign Language (ASL) sentences and grammatical judgment .

2.4 Skill Acquisition

Authors in [49] addressed that neuroplasticity relies on the age factor at which learning starts in several domains of skill acquisition. In studies that aspire to determine the connection between brain plasticity and age of maturity, most abilities are learned late in adulthood or childhood have been recognized to be a limit. According to [50], early sensory experiences tend to have an enormous capacity to improve neuronal circuitry in the early years of development, when the brain is inactive building up phase. Neuroimaging studies of language development concentrate on the variations between simultaneous and concurrent bilinguals in brain structure and function.It also discusses the idea of an optimal time in the production of languages. It thus gives the relationship between the acquisition era and the ultimate results [51].

Santiago Ramon Y Cajal (Nobel Prize winner) in 1894 presented that mental activity might prevail upon morphological changes in brain structure. Authors in [52] determined that the human brain structure expands and gets renormalized during skill acquisition. It is known as the expansion-renormalization model, according to which neural processes related to learning always adopt selection, sequence expansion, and renormalization [53]. The model foretells an initial rise in the density of grey matter, theoretically representing the growth of neural capital such as synapses, neurons, and glial cells. They are accompanied by a selection method operating on this new tissue. This results in a partial or complete return to the overall baseline volume after the selection has been completed. To date, improvements in brain structure have been reported on different time scales, such as several months of juggling training, medical examination study, space navigation training, learning of foreign languages, etc.

For any language learning, the age of its acquisition matters a lot. The literature shows the importance of age for learning a language; early language acquisition improves proficiency in a language. For first language learning, the social environment of infants also plays a significant role. Age of learning, nature of input language, and teaching strategy are also essential. Second language acquisition becomes easier if it is learned at an early age (before puberty). Because during this period, the brain has more plasticity and has much idea about language learning, which is experienced during first language learning. Vocabulary and grammar learning of the second language is easier if it is done simultaneously or sequentially of L1 in early childhood. Sign language acquisition is made later than infants, as born deaf children generally learn it. The age of sign language learning also affects its proficiency. Skill development or expertise learning is also depending on age and language proficiency before getting that skill. Learning at a later stage can be improved by doing morphological learning.

Table 2: Review of Language acquisition in brain

S. N.	Author	Task	Computation Method	Data Acquisition Method	Result
Language Acquisition					
1	P. K. Kuhl et. al., 2010[54]	Language and pre-reading in the age of 2, 3 and 5 years.	Alpha, beta and gamma rhythms analysis.	EEG/ERPs/MEG/fMRI/NIRS	Premature proficiency of the phonetic units of language demands social learning.
2	R. I. Mayberry et. al., 2011[29]	Grammatical judgment, American Sign Language, and phonemic hand judgment	t-statistics	fMRI data	The left lateralised activation pattern was observed
3	I. Kovelman et. al., 2012[14]	Language task and Rhythm Task	t-test analysis	fNIRS imaging	The right hemisphere overall displayed superior activation against the sluggish

					rhythmic stimulation, and the left hemisphere displayed better activation compared to the quicker and slower frequencies.
4	J. Martensson et. al., 2012[35]	Three months of extreme foreign language studies	t-test on cortical thickness	MRI	Anatomical variation in brain areas known for performing language roles during the learning of foreign languages.
5	S. Penicaud et. al., 2013[28]	American Sign Language (ASL)	voxel-based whole-brain correlational analysis.	fMRI	The functional as well as structural structure of the brain is impaired by lack of early language experience.
6	Miao Wei et. al., 2015[37]	Language history questionnaire task	Cluster size, t-score.	MRI/fMRI/ PET	In the right parietal cortex, earlier second-language sensitivity is correlated with greater volumes. Consistently, as AoA decreased, the cortical region of the right superior parietal lobule increased.
7	E. Plante et. al., 2015[30]	Learners who spoke English were exposed to Norwegian sentences.	GLM and ICA.	fMRI	The essence of the word input significantly affected the structure of the network used by the learners to acquire the properties of words in a natural language.
8	I. A. Mendez et. al., 2015[41]	The parents and twin's questionnaires containing standard demographic questions and question assessing zygosity	Multiple regression (MR) analyses.	Cognition Based Statistical data	Lower language anxiety is related to higher abilities. Bilingualism and the starting age of directed second language learning

					(ISLA) often tend to be unrelated to language-learned proficiency.
9	E. S. Nichols et. al., 2016[32]	Picture-word matching task	TBSS (Tract-Based Spatial Statistics), Monte Carlo simulation.	fMRI and DTI	Within bilingual brain, Proficiency and AoA clarify different functional and structural networks.
10	A. Shusterman et. al., 2016[20]	Environment-based and Body-based Frame-of-References	t-tests	Cognition Based Statistical data	Findings suggest that it would be much more common to use the front and back axes to communicate about space than to use the world's languages.
11	J. A. Berken et. al., 2017[49]	Review on brain structure and their function. Review specifically focus on sequential and simultaneous bilinguals.	Image based feature analysis of Grey matter density (GMD).	PET/fMRI/rs MRI	Simultaneous bilingual’s brain operation and framework seem to be most effectively organized. Sequential bilingual’s ability for neuroplasticity change is apparently more constrained.
12	E. Wenger et. al., 2017[52]	Training of skill development task	Voxel-based morphometry (VBM) analysis	MRI	The proposed prototype foretells an initial increase in the density of gray matter, theoretically reflecting the development of neural capital including neurons, glial cells, and synapses. After that a selection mechanism has been applied on the new tissue as a result of partial or complete return to the baseline of the

					gross volume, after the selection.
13	E. Partanen et. al., 2017[27]	Word form acquisition, associated with reading development	Event related field (ERF) waveform analysis.	MEG	The brains of the children seem more malevolent in learning novel word types than those of adults. A left-lateralized perisylvian network is often used by the developing brain to learn novel word types.
14	O. Kepinska et. al., 2017[43]	Grammar-learning task	Threshold-free cluster enhancement approach (TFCE), size of cluster, z-value	fMRI	With regard to functional communication, during grammar acquisition, brain networks involvement is correlated with one's language learning skills.
15	V. Havas et. al., 2017[31]	Early structural learning of a new language in adults.	Analysis of Variance (ANOVA) on reaction times (RTs)	EEG	Adult language learners can acquire new words, as well as new morphological rules.
16	M. Walton et. al., 2018[11]	Estimation of Speeded Naming and Phonological Processing in children	TBSS --- Tract Based Spatial Statistics.	DTI	Relationships seen in left ventricular pathways. Teenagers often rely on a large language processing network that gets more innovative with age.

3. Language Comprehensions

Language processing refers to how human words are used to express thoughts and emotions. We, as neuroscience researchers, are exploring how communications are processed and understood by the brain. Neuro-sensitive data-based studies have shown that most of the language processing tasks are performed in the cerebral cortex. Different regions handle most of the language roles. There are two well-identified regions considered essential to human language communication: Wernicke and the area of Broca. The accurate fasciculus is the brain region between the Wernicke and the Broca, connecting the two via bundles of nerve fibres. This part of the brain serves as a link between the two sections of the brain that deal with speech and communication.

Comprehension of sentences depends on deciding the thematic relationship between noun phrases, i.e., defining who is doing what to whom. A study in [55] based on fMRI evaluated the proper grammar and a key factor underlying the assessed output in the verbal working memory. Voxel-based grey matter morphometry disclosed that children’s ability to assign thematic roles, positively correlated with gray matter probability in the left inferior temporal gyrus as well as the left inferior frontal gyrus. The verbal work memory-related output in the left parietal operculum is positively associated with GMP and it extends to the posterior superior temporal gyrus. These brain regions are said to be differentially involved in complex sentence processing. Results indicate that there is a definite correspondence between GMP in language-relevant brain regions and differential cognitive abilities. They guide sentence comprehension of children.

EEG mu rhythms recording has been done at frontocentral electrodes. It is commonly taken as a measure of human motor cortical activity. It is modulated when the participants experience any old action, perform new action, or even speculate an action. A study in [56] recorded the modulation of mu rhythms in time-frequency (TF). At the same time, participants interpreted the language of motion, abstract language, and perceptive language. The findings indicate that mu repression is correlated with the language of practice rather than with abstract and perceptive language at fronto-locations. It also indicates that the activation occurs online through multiple words in the sentence, based on semantic integration.

At the time of sentence processing, the region left inferior frontal gyrus, upper temporal sulcus, and left basal ganglia, shown a systemic escalation in brain activity as a function of semantic structures, constituent size, and indicating their participation in syntactic computation. Experiments in [57] for non-spoken sign language on deaf participants highlight that the same language network has been found during reading and sign language processing. It also created a similar effect on the basal ganglia linguistic structure. This study also states that the cortical language area structure is much affected by the written language compared to sign language.

Based on evidence from neuroimaging, literature [58] reported both substantial overlap and unique linguistic cortical activation between the comprehension of observation of gestural behaviour and sign language. It is primarily observed that in the upper / lower parietal lobe and the fusiform gyrus, overlaps in cortical activation.

Authors in [59] found that ASL (American Sign Language) stimulated more strongly the middle STG (superior temporal gyrus) and left IFG (inferior frontal gyrus) in deaf native signers than gestures expressing roughly the same material. Here Graph Theoretical Analysis (GTA) is used on neural dependent cognition studies as essential alternative inactivation research.

A study in [60] illustrates the semantic and grammatical processing of accented speech, both native and international. Closer analysis of listeners indicates that those who did not understand the foreign accent correctly and who has familiar with the foreign accent exhibited ERP responses in both cases of error (semantic and grammatical). A listener who is not familiar with a foreign accent will not give the ERP response in case of a foreign-accented grammatical error. Still, late negativity may appear in semantic errors.

A study in [61] indicates that the brain's right hemisphere mechanisms are essential to triggering elements of event information that breach the linguistic meaning. The brain stimulates components of event knowledge that are semantically inconsistent during learning.

In [62], the authors state that the generation of online prediction for upcoming words depends on prosodic information available at the time of spoken language comprehension.

During serial visual presentation reading, the comprehension of spoken language may proceed incrementally than understanding for quantifier sentences. The analysis demonstrates that the comprehension of the spoken sentence continues fully incrementally; the results of true meaning in both negative and positive quantifier sentences are the same. It also suggests that people use the spoken language more effectively than written SVP feedback to produce online predictions about the coming words. During listening to natural speech, usually, learning continues more incrementally than during an ERP experiment with N400 results during SVP hearing.

The cortical representation of language comprehension becomes more focused in superior and middle temporal areas during late childhood and adolescence, according to researchers in [63].Higher language ability is correlated with greater right-hemispheric engagement during the listening of stories. Language comprehension is expressed more bilaterally than language output. The hemispheric dissociation with the development of the left hemispheric language, but the comprehension of the bilateral or right-hemispheric language is not unusual even in healthy right-handed subjects.

In [64], the authors experimented and found that the medial parietal lobe requires the production of referential words. First, a pairwise t-test has been done on the total activated cluster. Furthermore, every referential sub-condition is highly correlated with a more activated cluster than the non-reference conditions.

The prefrontal brain regions historically associated with language comprehension are the Wernicke area and the Broca area. Eleven subjects of the Curtiss- Yamada Comprehensive Language Evaluation Receptive (CYCLE-R) are taken to perform voxel-based lesion-symptom mapping (VLSM). The analysis of functional neuroimaging data highlights that injuries to five left hemisphere brain areas impressed execution on the CYCLE-R, including the posterior middle temporal gyrus and major white matter, the anterior superior temporal gyrus, the superior temporal sulcus, and angular gyrus, mid frontal cortex in BA 46 and BA 47 of the inferior frontal gyrus. The analysis also highlights that the middle temporal gyrus might have significance in word-level comprehension. However, other regions may have significance in sentence-level comprehension.

3.1 Bilingualism: A large portion of the world's inhabitants is bilingual and is flawlessly in over one language. A bilingual speaker routinely produces and understands, without difficulty, sentences that belong to two or more languages. Hence, knowing how two languages stick together in a single brain with slight disagreement or intrusion in both codes is a theoretical and applied question of great interest. But still, this is a research issue about whether early and/or prolonged exposure of two or more than two language processing in the single brain may lead to patterns of changes in brain activity.

Authors in [65] performed an experiment involving highly qualified bilingual Spanish monolinguals, and Spanish / Catalan made semantic and grammatical decisions in Spanish while being tested for fMRI. Grammatical findings exhibited improved activation in IFG (BA 45), occipital lobe (BA 18), and fusiform gyrus (BA 37) in the superior parietal lobe (SPL, BA 7). For the monolingual group, the cortical activations have been found in IFG (BA 45/46/9), SFG (BA 6), BA 8/32and BA 18/23/37). The study indicates that bilinguals are attracting new areas of the brain. However, these different areas depending on the learning age, language use, task circumstances, type of stimulus, cognitive/linguistic demands, and possibly the features and relative similarities between the languages bilingual speakers speak.

It has been observed that even though the single language has currently been used, but the bilinguals used two languages simultaneously at the time of speaking, reading, and listening. To promote lexical access and bilingual interfere comprehension during language processing, parallel activation has been done. Research also has highlighted that while bilinguals' process of visual words has been done, the co-activation of language experience and inhibitory regulation has been suggested. This has also been used to overcome non-target language competitions.

Authors in [66] suggested that the degree of language co-activation in bilingual spoken word comprehension is modulated by the amount of regular response to non-target language. In this case, the bilinguals are less affected by cross-language activation and could be more effective in conquering non-linguistic task intervention.

Findings in [67] highlight that instead of finding a few brain regions involvement, language processing can be regarded as a consequence of the collaboration network of brain areas. The fMRI experiment and analysis highlights that the activation of left-lateralized BA-44 and BA-45 to be in the case of these three tasks, such as suggesting language, phonological, and semanticized positions. This situation is called a receptive semanticized paradigm. However, they often included their right-like regions, which may be due to their role in executive control, focus, or memory manipulation. On the contrary, BA 22 activation dominated at the right. The authors propose that right BA22's contribution to language acquisition is an integral part of a broader chain comprising lower parietal lobule, bilateral STG, and left IFG.

EEG-based studies in [68] have taken two tasks: the reading and semantic decision. The different wave maps of experiment one indicate a frontal distribution of the disparity between new metaphoric sentences and literal. In the case of novel metaphoric sentences, the amplitudes of late positive complex (LPC) were reduced compared to anomalous sentences over parietal sites. Further, experiment two clearly lateralized the effect; however, in experiment 1, it is posed as a wider parietal distribution.

Authors in [69] performed an experiment focused on repeated transcranial magnetic stimulation (rTMS), taking lexical decisions against basic judging tasks. Findings provide evidence of an early motor cortex-TMS intervention protocol, which creates a left-lateralized task and contextual meaning improvement in latency responses. It is slowing down action-related word processing compared to faster abstract word reactions. The findings clearly state that the causal participation of different modality circuits in language understanding, suggesting that cognitive phenomena of high order are based on simple biological mechanisms.

In [70], the authors conducted a Near-Infrared Spectroscopy (NIRS) experiment using listening to English sentences with six separate speeches. The findings exhibited that Japanese people had understood speech several speech characteristics when amplitudes were expanded at specific frequency ranges. In NIRS measurement, a high Oxy-Hb concentration was noticed in most of the language areas (BA 45/44/22) due to an increase of amplitude in high frequency ranges from 7000 to 8500 Hz.

Study in [71] state that the two language sentence representation has common neural activation. The proposed method has been successfully implemented for observing the neural activity of a bilingual person. The mechanism behind the proposed system is to predict Portuguese sentences by using brain positions and NPSF (neutrally plausible semantic features) weights mechanism. The mapping between NPSF and the neural activation patterns can be obtained in either language from any group of participants and yields positive activation prediction produced by new word composed sentences.

A study based on an EEG experiment in [72] says a strong correlation between semantic unification and gamma-band oscillations. In contrast, beta-band oscillation has a strong syntactic unification correlation.

Authors in [73] Introduce functional and anatomical connectivity to research a cognitive feature of interest sub-serving the network topology. In this research, the author analyzes the direct interaction between several network nodes of the human brain. Further, the multivariate method of dPC (partial directional correlation) has been used to analyse functional MRIs' time series data. A region-to-region probabilistic fibre tracking is performed on diffusion tensor image data to classify the most likely structural white matter tracts mediating functional interactions. The mixed approach is extended to two stages of auditory comprehension: the lowest understanding of speech and higher awareness of speech. They were combining and applying interaction tracts of dPC and dorsal long and short reach and commissural fibres.

The research in [74] suggested how the degree to which results relate oscillatory neural dynamics in the beta and gamma frequency. It ranges to the language comprehension of the sentencing stage can be given a coherent description within a predictive coding system. They have proposed that beta activity reflects both top-down propagation and the active maintenance of the current Neurocognitive Network (NCN). The NCN is liable for sentence-level meaning construction and representation. However, the top-down propagation helps in processing hierarchy at lower levels.

The study in [75] discovered the fronto-temporal resting-state connectivity development at the age of five years or more has been examined the association of intrinsic low-frequency BOLD oscillations in language-related regions. The findings of right and left IFG inter-hemispheric coupling between a five-year-old person and adults long-range connectivity on IFG and pSTS within the left hemisphere were consistent with previous low-frequency fluctuations (LFFs) analysis of fMRI data. The findings support the idea that frontal-temporal functional communication is crucial in processing complex syntactic sentences in the language network in the left hemisphere. Stronger long-range connectivity in adults leads to a proper discriminating left-hemispheric language network developmental trajectory.

Table 3: Review of Language comprehension in brain

S.N.	Author	Task	Computation Method	Data Acquisition Method	Result
Language Comprehension					
1	N. F. Dronkers et. al., 2004[76]	English sentence comprehension	t-test	fMRI/MRI	The middle temporal gyrus may be more relevant for word level comprehension, while the other areas may play a greater contribution at the sentence level comprehension.
2	K. Lidzba et. al., 2011[63]	Beep stories (Language Comprehension) and	Statistical analysis (t-tests).	fMRI	Only in the language comprehension test was verbal IQ correlated

		language production (Vowel Identification) tasks.			with lateralisation, with higher verbal IQ involved with more right-hemispheric partaking.
3	A. Fengler et. al., 2015[55]	Standardized sentence comprehension test, to assess the participant's grammatical proficiency.	Voxel-based morphometry analysis (z-score, cluster size).	MRI	The GMP of children in language-relevant brain regions has a strong connection with the distinctive cognitive capacity that directs their comprehension of this sentence.
4	A. G. Lewis et. al., 2015[72]	Semantic coherence in short stories, and other language comprehension tasks	beta and gamma oscillatory activity	EEG/MEG	Alternative solution to link the gamma and beta oscillations during language comprehension for maintenance and prediction.
5	P. Roman et. al., 2015[65]	Semantic infringement, loss of grammar and state of charge.	t-score	fMRI	Strong bilingualism affects the brain and cognitive processes during comprehension of phrase even in their native language. On the contrary, brain is not limited to a single region through stimulation in the bilingual.
6	I. Moreno et. Al., 2015[56]	Reading action language	Event-related potential (ERP) analysis and Time-frequency (TF) analysis	EEG	Action language comprehension stimulates motor networks throughout the human brain.
7	R. Metusalem et. Al., 2016[61]	Expected, event-related, event-unrelated words and response to understanding questions are used	Various statistical analyses were operated on mean ERP voltage measures	EEG	Foster our understanding of event information activation of neural basis and advance our comprehension of how an event awareness is activated in incremental understanding during creation of perceptions and elaborate inferences

					more generally.
8	D. Freunberger et. al., 2016[62]	N400 event-related potentials (ERP)	Linear Mixed Effects (LME) Models Using S4 Classes.	EEG	Person can speak language more efficiently than written SVP feedback to produce online predictions of coming words.
9	Y. Yang et. al., 2017[71]	English and Portuguese language reading	BOLD activation analysis	fMRI	Proven ability to predict meta-language through cultures, people and bilingual status.
10	S. Grey et. al., 2017[60]	Foreign-accented and native-accented speech	Mean ERP amplitudes	EEG/ERP	Provides new insight into the effect on language acquisition of neural associations of listener experience and the state of foreign speakers.
11	L. Liu et.al., 2017[58]	Learning sign language by non-signers and signers' sign language understanding.	GTA: Graph Theoretical Analysis	fMRI	When viewing sign language, hearing signers and non-signers presented similar cortical activations.
12	C. Brodbeck et. al., 2017[77]	Visuo-spatial referential Domains	t-tests	MEG/EEG	Reports the medial parietal lobe participates in the production of referential words.
13	P. Chen et. al., 2017[66]	Word pairs of inter-lingual homophones between English and Korean	ANOVAs with relatedness	Event-related potential (ERP)	The degree of linguistic co-activation in bilingual spoken word understanding is modulated by the amount of daily exposure to the non-target language.
14	N. Vukovic et. al., 2017[78]	Action words, abstract words and pseudo words	ANOVA, with the independent factors of Task	repetitive transcranial magnetic stimulation (rTMS)	Cortical motor regions play a vital role in understanding language.
15	K. Inada et. al., 2017 [70]	English speech task	Enhanced amplitudes	Near-infrared spectroscopy system	English speeches with enhanced amplitudes can affect brain function activation in language processing

				(NIRS)	and help to better understand the spoken English .
16	A. Moreno et.al., 2018[57]	Sign language paradigm and written French stimuli	Z-score	MRI/fMRI	Here it is identified that the language network comprises the left superior temporal sulcus, inferior frontal gyrus, and basal ganglia. It is systematically involved in combinatorial language operations.
17	R. Alemi et. al., 2018[67]	Word Production (WP) task, Auditory Responsive Naming (ARN) paradigm, Visual Semantic Decision (VSD) paradigm	Group ICA	fMRI	The language function should be regarded as the result of a network of brain regions collaborating.
18	K. Rataj et. al., 2018[68]	Semantic decision and a reading task	t-test	EEG	The Late-Positive-Complex (LPC) pattern is modulated by both conventionality and task demand.

4 Data Acquisition and Analysis Techniques

4.1 Data Acquisition

It has been observed in the last few decades that the rapid development of human brain language processing or brain study in non-invasive modus operandi is considered as an alternative to postmortem. The main non-invasive techniques for language processing are EEG (Electroencephalography), ERPs (Event-related Potentials), MEG (Magnetoencephalography), rsMRI (structural/resting-state Magnetic Resonance Imaging)[107], fMRI (functional Magnetic Resonance Imaging), NIRS (Near Infrared Spectroscopy), DTI (Diffusion Tensor Imaging), PET (Positron emission tomography) and many more.

4.1.1 MRI (Magnetic resonance imaging): Combining MEG and/or EEG, magnetic resonance imaging (MRI) can provide static structural/anatomical brain images. In this method, we can see the structural difference in the human brain across the whole lifespan. During the last few decades, structural MRI has also been observed to find the possibility of adults' second language learning of phonetics [79]. Research [80] also validated the previous study and stated that the structural MRI could measure the size of various brain structures in adult or young infants. It has also been used for future learning ability predictions. Using this method, the recording of spatial localization of brain activity can be improved when the MEG or EEG has detected the physiological activity.

4.1.2 fMRI (Functional magnetic resonance imaging): It is a common tool for human neuroimaging since it offers high spatial resolution maps of neural activity across the total brain. [81]. The fMRI senses changes in blood oxygenation that happen in the neural activation reaction.

Neural effects occur in milliseconds, but the changes in blood oxygenation extend over many seconds, greatly restricting the temporal resolution of fMRI. fMRI learning let the exact location of brain activity and some ground-breaking study illustrate remarkable similarities in the language-responsive structures in infants and adults. [82-83, 106].

4.1.3 EEG (Electroencephalography): It is a non-invasive technique used for recording the electrical activity of the brain. It is also called electrophysiological monitoring technique. In this technique, the electrodes are fixed on the scalp. With the help of electrodes placed on the scalp, brain activity has been recorded in terms of voltage variation. It has also been observed that sometimes, it work in an invasive manner [84].

4.1.4 ERPs (Event-related Potentials): It has been used for infants and young children's speech and language processing [85-87]. It also works similarly to the EEG and records the brain's electrical activity that helps find the specific sensory stimulus or the cognitive process of the brain. During the recording process sensor has been placed on the scalp of the infant. The recording stores the information related to the behaviour of the neural network, and the performance of the neural network has been at every change of voltage during the cortical neural activity in a synchronous manner.

4.1.5 MEG (Magnetoencephalography): It is a technique for brain imaging for tracking the excellent temporal resolution of brain activity. The brain activity has been recorded with the help of SQUID sensors situated inside the MEG helmet. The main job of MEG is to evaluate the minute magnetic fields that are associated with brain electrical signals generated during cognitive tasks, motor, or sensory processes of the brain. MEG facilitates the exact location of the neural currents accountable for the magnetic field [88-89]. The use of modern head monitoring systems and MEG illustrate phonetic recognition in infants and newborns in their first year of life.

4.1.6 NIRS (Near-Infrared Spectroscope): It is used to measure the cerebral hemodynamic response of neural activity of the brain. It utilized the absorption of light that is sensitive to haemoglobin concentrations [90]. It is used to monitor changes in the amounts of blood oxygen and deoxy-haemoglobin in the brain. It has also been used to monitor the overall increases in blood volume in various cerebral cortex regions using near-infrared radiation. With the help of NIRS, we can determine the blood haemoglobin level in a specific region of the brain. NIRS using near-infrared light measures changes of total blood volume variations in different areas of the cerebral cortex and changes in blood oxy- and deoxy-haemoglobin concentrations in the brain. By continuously monitoring blood haemoglobin levels, the NIRS system can determine the activity in specific brain regions. In the first two years of life, studies have started to surface on children and test infants' response to phonemes, motherese, and forward versus reversed sentences.

4.1.7 DTI (Diffusion Tensor Imaging): Diffusion tensor imaging is a neuro-imaging method that uses magnetic resonance imaging (MRI) to characterise micro-structural changes or differences in relation to neuropathology and treatment. It may be used to determine the magnitude, degree of anisotropy, and directional diffusion orientation. It aids in determining the position, direction, and anisotropy of the brain's white matter tracts. It is thought to be a more sensitive technique for investigating both normal and congenital brain development problems [91].

4.1.8 PET (Positron emission tomography): It tests pollutants from metabolically active chemicals injected into the bloodstream, which are radioactively labelled. In this method, the emission data are processed by a computer to create multi-dimensional images of the chemical distribution across the brain [92].

4.2 Data Analysis

Functional magnetic resonance imaging is a safe and non-invasive way to measure brain functional activity with the signal generated by the brain and the signal changes during brain activity. The method has become an omnipresent instrument of fundamental, cognitive, and clinical neuroscience. This approach has been used to calculate the little changes in metabolism occurring in the active region of the brain. We analyze the fMRI data to identify the brain regions involved in a function or to determine the changes that occur due to brain lesions in brain activities.

4.2.1 Statistical Analysis Methods

The efficiency of the fMRI images is enhanced during the pre-processing stages. After that, statistical analysis is attempted to establish which voxels the stimulus stimulates. Many of the fMRI studies are focused on the association between the hemodynamic response process and stimulation. Activation determines the changes in the images to local severity. In this field of study, the methods can be categories into univariate and multivariate methods. The univariate method is used for hypothesis testing, whereas the multivariate method is used for exploration.

4.2.1.1 The univariate methods seek to define which voxels, provided one signal model, can be defined as disabled. It allows response parameterization and then model parameter estimation. The Generalized Linear Model (GLM) is a method of univariate analysis [93].

4.2.1.2 Multivariate approaches are often applied to the analysis of fMRI data. This process first collects data from the sample, then performs the experimental analysis based on prior knowledge. To identify the characteristics of fMRI data, the de correlation, similarity measures, and structural independence properties have been used by this approach. The voxel-wise statistical analysis has been done in univariate methods, whereas in this method, the statistical inference of the entire brain has been produced during the spatial response of the pattern given by the brain [94]. Multivariate method of analysis involves Principal Component Analysis, Independent Component Analysis, and MVPA(Multi-Voxel Analysis of Patterns). In MVPA feature, Selection is made by approaches that pick the voxels that have more knowledge on the mental mission.
In this approach, the feature selection has been made using the following methods: the t-test, f-score, ANOVA, RFE (recursive feature evaluation), Voxel activation criteria and SVM (support vector machines)[95].

5 Neuroimaging Software tools

Software tools are used to analyse and visualise neuroimages to study the structure and function of the brain. Some of the popular neuroimaging software tools are AFNI (Analysis of Functional NeuroImages), BrainSuite [96], CONN (Functional Connectivity Toolbox), EEGLAB, FreeSurfer, FSL, and SPM (Statistical parametric mapping), etc.

Table 3: Tools for Neuro-data analysis

S.No.	Tool Name	Availability	Input Data	Results
1.	3D Slicer (Slicer) [97]	Free and open source software	Image	Scientific visualization and image computing

2.	Analysis of Functional NeuroImages (AFNI)[98]	Open source environment	functional MRI data	Mapping human brain activity
3.	CONN[99]	Matlabbased cross-platform imaging software	fMRI and resting state MRI data	Computation, display and analysis
4.	EEGNET [100]	MATLAB toolbox	Data from EEG, MEG, and other electrophysiological signals	ICA, time or frequency analysis, several modes of data visualization and artefact rejection.
5.	FreeSurfer[101]	Brain imaging software package	MRI scan data	Functional brain mapping helps in visualizing the functional regions of the cerebral cortex.
6.	Statistical parametric mapping (SPM)[102]	Matlab based toolbox	fMRI or PET	Statistical analysis
7.	FMRIB Software Library (FSL)[103]	Freely available software library	functional, structural and diffusion MRI brain imaging data	Image and statistical analysis
8.	Neuroimaging Informatics Tools and ResourcesClearinghouse (NITRC)[104]	Computational neuroscience tools and resources	MR, PET/SPECT, CT, EEG/MEG, optical imaging	Facilitating interactions between researchers and developers

6: Artificial intelligence based computational techniques for neuroscience data:

In recent years, several neuro data came into existence. This study observed that with the help of machine learning techniques and different types of neuroimaging variants can be integrated to produce more accurate outcomes as the variants contain supplementary information. It shows how the functionality of the injured brain due to aphasia translate into language function. Again it is found that to understand the neurobiological substrates of aphasia, various neuroimaging variants such as fMRI, DTI are used.[108]

To analyze the ageing effect and head motion, Machine Learning is used. For analyzing the brain data, the fMRI images assisted in finding functional connectivity in normal and aged brains.

Machine learning and statistical approaches can be used to investigate the more responsive parameters connected to signal distortion. For feature elimination support vector machine was used.[109]

In this study, it is observed that the machine learning technique rs-fMRI can be used. Supervised learning is applied to study brain development and ageing, neurological and psychiatric disorders. Unsupervised learning is used to explore dynamic functional connectivity patterns and spatial patterns.[110]

Because of its dimensionality, Machine learning techniques can be used on EEG data. It may treat EEG data as a pattern. It could be a more informative data interpretation approach Instead of considering each EEG unit individually. At the individual level, to extract the response and predict the data, Machine learning approaches are more helpful.[111]

Machine learning techniques like Convolutional Neural Networks, neural networks, KNN, Random forest, SVM were used to analyze EEG data and concluded that meditation and yoga make the brain healthy and active.[112]

This study was conducted to understand language comprehension; a combined EEG and MEG data were used, two paradigms, multi feature oddball paradigm and an equiprobable design were created. A machine learning-based classification technique was used to analyze the data. Concluded that by using the equiprobable design, important language processes could be assessed in a short time [113]

In this study, using diffusion tensor imaging, machine learning was applied to the patients with a sleep behaviour disorder and idiopathic rapid eye movement. Using traditional diffusion tensor imaging and structural connectomic profiles, we next employed machine learning analysis with a support vector machine technique to identify patients with an idiopathic sleep behaviour disorder. It was demonstrated effectively that a machine learning algorithm using diffusion tensor imaging recognized patients with an idiopathic sleep behaviour disorder. The maximum classification accuracy attained using the support vector machine approach was 87.5 percent, with an AUC of 0.900.[114]

Under this study, it was found that the fNIRS imaging technique captures hemodynamic responses of the brain. The hemodynamic responses or blood oxygenation level- dependency of the brain are imaged using functional near-infrared spectroscopy (fNIRS), a brain imaging technique. The fNIRS signal can be used to distinguish different mental states using machine learning (ML). To create the feature matrix, eight essential features from the hemodynamic brain signals and trained six distinct k-nearest neighbours (k-NN) ML classifiers. The method is promising for real-time mental workload classification employing a portable fNIRS sensor combined with modern machine learning techniques.[115]

7 Conclusion

In this article, we have discussed how the brain behaves while language-related tasks like language acquisition and language comprehension. We have found that most of the language-related tasks are performed by Broca's and Wernicke's areas in the brain. In terms of Broadman Areas BA 22, BA44 and BA 45 are main ROIs for language-related tasks. Literature also reveals that most of the other parts of the brain are also got activated while language comprehension depending upon the syntax and semantic of the sentences. IFG and STG also play an important role in sign language comprehension. Studies also show that bilingual brains are more active than monolingual brains. We have also discussed different data acquisition techniques for the study of brain-behavior. Different statistical analysis techniques are also discussed, which is used for neuro data analysis.

References

[1] Friederici, Angela D. "The brain basis of language processing: from structure to function." Physiological reviews 91.4 (2011): 1357-1392.
[2] Sakai, Kuniyoshi L. "Language acquisition and brain development." Science 310.5749 (2005): 815-819.
[3] E. H. Lenneberg, The biological foundations of language: 154-155. 1967.
[4] E. L. Newport and N. York, “Language development, critical periods in,” Encycl. Cogn. Sci., pp. 737–740, 2003.
[5] J. R. Hurford, “The Evolution of the Critical Period for Language-Acquisition,” Cognition, vol. 40, no. 3, pp. 159–201, 1991.
[6] J. Gallaso, “First and second language acquisition,” 2003. Retrieved from http://www.csun.edu/~galasso/lang1.htm.
[7] B. F. Skinner, “Cognitive science and behaviourism,” British Journal of Psychology, vol. 76, no. 3. pp. 291–301, 1985.
[8] N. Chomsky, “Verbal behaviour,” Language (Baltim)., vol. 35, no. 1, pp. 26–58, 1959.
[9] Pascual-Leone, Juan. "Vygotsky, Piaget, and the problems of Plato." Swiss Journal of Psychology 55 (1996): 84-92.
[10] Lightbown, Patsy M., and Nina Spada. How languages are learned 4th edition-Oxford Handbooks for Language Teachers. Oxford university press, 2013.
[11] M. Walton, D. Dewey, and C. Lebel, “Brain white matter structure and language ability in preschool-aged children,” Brain Lang., vol. 176, no. September 2016, pp. 19–25, 2018.
[12] J. M. Carroll, B. Maughan, R. Goodman, and H. Meltzer, “Literacy difficulties and psychiatric disorders: Evidence for comorbidity,” J. Child Psychol. Psychiatry Allied Discip., vol. 46, no. 5, pp. 524–532, 2005.
[13] M. Smits, L. C. Jiskoot, and J. M. Papma, “White Matter Tracts of Speech and Language.” Semin. Ultrasound CT MRI, vol. 35, no. 5, pp. 504–516, 2014.
[14] I. Kovelman, K. Mascho, L. Millott, A. Mastic, B. Moiseff, and M. H.Shalinsky, “At the rhythm of language: Brain bases of language-related frequency perception in children,” Neuroimage, vol. 60, no. 1, pp. 673–682, 2012.
[15] U. Goswami, “A temporal sampling framework for developmental dyslexia,” Trends Cogn. Sci., vol. 15, pp. 3–10, 2011.
[16] L. A. Petitto, How the brain begets language: on the neural tissue underlying human language acquisition. Cambridge, UK: The Cambridge Companion to Chomsky. Cambridge University Press, 2005.
[17] A. L. Giraud, A. Kleinschmidt, D. Poeppel, T. E. Lund, R. S. Frackowiak, and H. Laufs, “Endogenous cortical rhythms determine cerebral specialization for speech perception and production,” Neuron, vol. 56, pp. 1127–1134, 2007.
[18] H. Luo, Z. Liu, and D. Poeppel, “Auditory cortex tracks both auditory and visual stimulus dynamics using low-frequency neuronal phase modulation,” PLoS Biol, vol. 8, 2010.

[19] Morillon, Benjamin, et al. "Neurophysiological origin of human brain asymmetry for speech and language." Proceedings of the National Academy of Sciences 107.43 (2010): 18688-18693.
[20] Shusterman, Anna, and Peggy Li. "Frames of reference in spatial language acquisition." Cognitive Psychology 88 (2016): 115-161.
[21] S. C. Levinson, “Frames of reference and Molyneux’s question: Cross-linguistic evidence,” Language and space, P. Bloom, L. N. Peterson, and M. F. Garrett, Eds. Cambridge: MIT Press, 1996, pp. 109–169.
[22] Levinson, Stephen C., and Stephen C. Levinson. Space in language and cognition: Explorations in cognitive diversity. Vol. 5. Cambridge University Press, 2003.
[23] A. Majid, M. Bowerman, S. Kita, D. Haun, and S. Levinson, “Can language restructure cognition? The case for space,” Trends Cogn. Sci., vol. 8, no. 3, pp. 108–114, 2004.
[24] E. Pederson, E. Danziger, D. Wilkins, S. Levinson, S. Kita, and G. Senft, “Semantic typology and spatial conceptualization,” Language (Baltim)., vol. 74, no. 3, pp. 557–589, 1998.
[25] D. B. M. Haun, C. J. Rapold, J. Call, G. Janzen, and S. C. Levinson, “Cognitive cladistics and cultural override in Hominid spatial cognition,” in Proceedings of the National Academy of Sciences of the United States of America, 2006, pp. 17568–17573.
[26] J. Pyers, A. Shusterman, A. Senghas, E. A. Spelke, and K. Emmorey, “Evidence from users of an emerging sign language reveals that language supports spatial cognition,” in Proceedings of the National Academy of Sciences, 2010, pp. 12116–12120.
[27] E. Partanen, A. Leminen, S. de Paoli, A. Bundgaard, O. S. Kingo, P. Krøjgaard, and Y. Shtyrov, “Flexible, rapid and automatic neocortical word form acquisition mechanism in children as revealed by neuromagnetic brain response dynamics,” Neuroimage, vol. 155, no. April, pp. 450–459, 2017.
[28] S. Pénicaud, D. Klein, R. J. Zatorre, J. K. Chen, P. Witcher, K. Hyde, and R. I. Mayberry, “Structural brain changes linked to delayed first language acquisition in congenitally deaf individuals,” Neuroimage, vol. 66, pp. 42–49, 2013.
[29] R. I. Mayberry, J. K. Chen, P. Witcher, and D. Klein, “Age of acquisition effects on the functional organization of language in the adult brain,” Brain Lang., vol. 119, no. 1, pp. 16–29, 2011.
[30] E. Plante, D. Patterson, R. Gómez, K. R. Almryde, M. G. White, and A. E. Asbjørnsen, “The nature of the language input affects brain activation during learning from a natural language,” J. Neurolinguistics, vol. 36, pp. 17–34, 2015.
[31] V. Havas, M. Laine, and A. Rodríguez Fornells, “Brain signatures of early lexical and morphological learning of a new language,” Neuropsychologia, vol. 101, no. April, pp. 47–56, 2017.
[32] E. S. Nichols and M. F. Joanisse, “Functional activity and white matter microstructure reveal the independent effects of age of acquisition and proficiency on second-language learning,” Neuroimage, vol. 143, pp. 15–25, 2016.
[33] P. Li, J. Legault, and K. A. Litcofsky, “Neuroplasticity as a function of second language learning : Anatomical changes in the human brain,” Cortex, vol. 58, pp. 301–324, 2014.

[34] Newman, A. J., Tremblay, A., Nichols, E. S., Neville, H. J., & Ullman, M. T. (2012). The influence of language proficiency on lexical semantic processing in native and late learners of English. Journal of Cognitive Neuroscience, 24(5), 1205-1223.

[35] J. Mårtensson, J. Eriksson, N. C. Bodammer, M. Lindgren, M. Johansson, L. Nyberg, and M. Lövdén, "Growth of language-related brain areas after foreign language learning," Neuroimage, vol. 63, no. 1, pp. 240–244, 2012.

[36] M. Stein, A. Federspiel, T. Koenig, M. Wirth, W. Strik, R. Wiest, D. Brandeis, and T. Dierks, "Structural plasticity in the language system related to increased second language proficiency," Cortex, vol. 48, no. 4, pp. 458–465, 2012.

[37] M. Wei, A. A. Joshi, M. Zhang, L. Mei, F. R. Manis, Q. He, R. L. Beattie, G. Xue, D. W. Shattuck, R. M. Leahy, F. Xue, S. M. Houston, C. Chen, Q. Dong, and Z. L. Lu, "How age of acquisition influences brain architecture in bilinguals," J. Neurolinguistics, vol. 36, pp. 35–55, 2015.

[38] V. Ressel, C. Pallier, N. Ventura-Campos, B. Diaz, A. Roessler, C. Avila, and N. Sebastian-Galles, "An Effect of Bilingualism on the Auditory Cortex," J. Neurosci., vol. 32, no. 47, pp. 16597–16601, 2012.

[39] Zou, L., Ding, G., Abutalebi, J., Shu, H., & Peng, D. (2012). Structural plasticity of the left caudate in bimodal bilinguals. Cortex, 48(9), 1197-1206.

[40] P. A. Della Rosa, G. Videsott, V. M. Borsa, M. Canini, B. S. Weekes, R. Franceschini, and J. Abutalebi, "A neural interactive location for multilingual talent," Cortex, vol. 49, no. 2, pp. 605–608, 2013.

[41] Antón-Méndez, I., Ellis, E. M., Coventry, W., Byrne, B., & Van Daal, V. H. (2015). Markers of success: A study of twins' instructed second language acquisition. Learning and Individual Differences, 42, 44-52.

[42] M. Coventry, I. Anton-Mendez, E. M. Elis, C. Levisen, B. Byrne, and V. H. O. Van Daal, "The etiology of individual differences in second language acquisition in australian school students: A behavior-genetic study," Lang. Learn., vol. 62, no. 3, pp. 880–901, 2012.

[43] O. Kepinska, M. de Rover, J. Caspers, and N. O. Schiller, "Whole-brain functional connectivity during acquisition of novel grammar: Distinct functional networks depend on language learning abilities," Behav. Brain Res., vol. 320, pp. 333–346, 2017.

[44] R. I. Mayberry, "When timing is everything: Age of first language acquisition effects on second language learning," Appl. Psycholinguist., vol. 282007/12/, pp. 537–549, 2007.

[45] R. I. Mayberry, "Early Language acquisition and Adult Language Ability: What Sign Language Reveals about the Critical Period for Language," in Deafness, vol. 2, 2009, pp. 175–176.

[46] Kassubek, J., Hickok, G., & Erhard, P. (2004). Involvement of classical anterior and posterior language areas in sign language production, as investigated by 4 T functional magnetic resonance imaging. Neuroscience letters, 364(3), 168-172.

[47] McCullough, S., Emmorey, K., & Sereno, M. (2005). Neural organization for recognition of grammatical and emotional facial expressions in deaf ASL signers and hearing nonsigners. Cognitive Brain Research, 22(2), 193-203..

[48] K. L. Sakai, Y. Tatsuno, K. Suzuki, H. Kimura, and Y. Ichida, “Sign and speech: Amodal commonality in left hemisphere dominance for comprehension of sentences,” Brain, vol. 128, pp. 1407–1417, 2005.
[49] J. A. Berken, V. L. Gracco, and D. Klein, “Early bilingualism, language attainment, and brain development,” Neuropsychologia, vol. 98, no. September 2016, pp. 220–227, 2017.
[50] Butz, M., Steenbuck, I. D., & van Ooyen, A. (2014). Homeostatic structural plasticity increases the efficiency of small-world networks. Frontiers in synaptic neuroscience, 6, 7
[51] Li, G., Nie, J., Wang, L., Shi, F., Lin, W., Gilmore, J. H., & Shen, D. (2013). Mapping region-specific longitudinal cortical surface expansion from birth to 2 years of age. Cerebral cortex, 23(11), 2724-2733.
[52] Wenger, E., Brozzoli, C., Lindenberger, U., & Lövdén, M. (2017). Expansion and renormalization of human brain structure during skill acquisition. Trends in cognitive sciences, 21(12), 930-939..
[53] H. Makino, E. J. Hwang, N. G. Hedrick, and T. Komiyama, “Circuit Mechanisms of Sensorimotor Learning,” Neuron, vol. 92, no. 4, pp. 705–721, 2016.
[54] P. K. Kuhl, “Brain Mechanisms in Early Language Acquisition,” Neuron, vol. 67, no. 5, pp. 713–727, 2010.
[55] Fengler, A., Meyer, L., & Friederici, A. D. (2015). Brain structural correlates of complex sentence comprehension in children. Developmental cognitive neuroscience, 15, 48-57.
[56] I. Moreno, M. de Vega, I. León, M. Bastiaansen, A. Glen Lewis, and L. Magyari, “Brain dynamics in the comprehension of action-related language. A time-frequency analysis of mu rhythms,” Neuroimage, vol. 109, pp. 50–62, 2015.
[57] A. Moreno, F. Limousin, S. Dehaene, and C. Pallier, “Brain correlates of constituent structure in sign language comprehension,” Neuroimage, vol. 167, no. April 2017, pp. 151–161, 2018.
[58] L. Liu, X. Yan, J. Liu, M. Xia, C. Lu, K. Emmorey, M. Chu, and G. Ding, “Graph theoretical analysis of functional network for comprehension of sign language,” Brain Res., vol. 1671, pp. 55–66, 2017.
[59] A. J. Newman, T. Supalla, N. Fernandez, E. L. Newport, and D. Bavelier, “Neural systems supporting linguistic structure , linguistic experience , and symbolic communication in sign language and gesture,” pp. 1–6, 2015.
[60] S. Grey and J. G. van Hell, “Foreign-accented speaker identity affects neural correlates of language comprehension,” J. Neurolinguistics, vol. 42, pp. 93–108, 2017.
[61] R. Metusalem, M. Kutas, T. P. Urbach, and J. L. Elman, “Hemispheric asymmetry in event knowledge activation during incremental language comprehension: A visual half-field ERP study,” Neuropsychologia, vol. 84, pp. 252–271, 2016.
[62] D. Freunberger and M. S. Nieuwland, “Incremental comprehension of spoken quantifier sentences: Evidence from brain potentials,” Brain Res., vol. 1646, pp. 475–481, 2016.
[63] K. Lidzba, E. Schwilling, W. Grodd, I. Krägeloh-Mann, and M. Wilke, “Language comprehension vs. language production: Age effects on fMRI activation,” Brain Lang., vol. 119, no. 1, pp. 6–15, 2011.
[64] C. Brodbeck and L. Pylkkänen, “Language in context: Characterizing the comprehension of referential expressions with MEG,” Neuroimage, vol. 147, no. December 2016, pp. 447–460, 2017.

[65] P. Román, J. González, N. Ventura-Campos, A. Rodríguez-Pujadas, A. Sanjuán, and C. Ávila, "Neural differences between monolinguals and early bilinguals in their native language during comprehension," Brain Lang., vol. 150, pp. 80–89, 2015.

[66] P. Chen, S. C. Bobb, N. Hoshino, and V. Marian, "Neural signatures of language co-activation and control in bilingual spoken word comprehension," Brain Res., vol. 1665, pp. 50–64, 2017.

[67] R. Alemi, S. A. H. Batouli, E. Behzad, M. Ebrahimpoor, and M. A. Oghabian, "Not single brain areas but a network is involved in language: Applications in presurgical planning," Clin. Neurol. Neurosurg., vol. 165, no. January, pp. 116–128, 2018.

[68] K. Rataj, A. Przekoracka-Krawczyk, and R. H. J. van der Lubbe, "On understanding creative language: The late positive complex and novel metaphor comprehension," Brain Res., vol. 1678, pp. 231–244, 2018.

[69] N. Vukovic, M. Feurra, A. Shpektor, A. Myachykov, and Y. Shtyrov, "Primary motor cortex functionally contributes to language comprehension: An online rTMS study," Neuropsychologia, vol. 96, no. January, pp. 222–229, 2017.

[70] K. Inada and A. K. Yamazaki, "Verification of Amplitude Enhancement Effects on comprehensions of English speeches and brain functions," Procedia Comput. Sci., vol. 112, pp. 1926–1934, 2017.

[71] Y. Yang, J. Wang, C. Bailer, V. Cherkassky, and M. A. Just, "Commonality of neural representations of sentences across languages: Predicting brain activation during Portuguese sentence comprehension using an English-based model of brain function," Neuroimage, vol. 146, no. May 2016, pp. 658–666, 2017.

[72] A. G. Lewis, L. Wang, and M. Bastiaansen, "Fast oscillatory dynamics during language comprehension: Unification versus maintenance and prediction?," Brain Lang., vol. 148, pp. 51–63, 2015.

[73] D. Saur, B. Schelter, S. Schnell, D. Kratochvil, H. Küpper, P. Kellmeyer, D. Kümmerer, S. Klöppel, V. Glauche, R. Lange, W. Mader, D. Feess, J. Timmer, and C. Weiller, "NeuroImage Combining functional and anatomical connectivity reveals brain networks for auditory language comprehension," vol. 49, pp. 3187–3197, 2010.

[74] A. G. Lewis and M. Bastiaansen, "ScienceDirect Special issue : Review A predictive coding framework for rapid neural dynamics during sentence-level language comprehension," vol. 8, 2015.

[75] Y. Xiao, A. D. Friederici, D. S. Margulies, and J. Brauer, "Development of a selective left-hemispheric fronto-temporal network for processing syntactic complexity in language comprehension," Neuropsychologia, vol. 83, pp. 274–282, 2016.

[76] N. F. Dronkers, D. P. Wilkins, R. D. Van Valin, B. B. Redfern, and J. J. Jaeger, "Lesion analysis of the brain areas involved in language comprehension," Cognition, vol. 92, no. 1–2, pp. 145–177, 2004.

[77] C. Brodbeck and L. Pylkkänen, "Language in context: Characterizing the comprehension of referential expressions with MEG," Neuroimage, vol. 147, no. September 2016, pp. 447–460, 2017.

[78] N. Vukovic, M. Feurra, A. Shpektor, A. Myachykov, and Y. Shtyrov, "Primary motor cortex functionally contributes to language comprehension: An online rTMS study," Neuropsychologia, vol. 96, no. September 2016, pp. 222–229, 2017.

[79] N. Golestani and C. Pallier, "Anatomical Correlates of Foreign Speech Sound Production," no. April 2007, pp. 929–934, 2018.
[80] S. Ortiz-Mantilla, M. sun Choe, J. Flax, P. E. Grant, and A. A. Benasich, "Associations between the size of the amygdala in infancy and language abilities during the preschool years in normally developing children," Neuroimage, vol. 49, no. 3, pp. 2791–2799, 2010.
[81] Logothetis, N. K., Pauls, J., Augath, M., Trinath, T., & Oeltermann, A. (2001). Neurophysiological investigation of the basis of the fMRI signal. Nature, 412(6843), 150-157.
[82] G. Dehaene-Lambertz, L. Hertz-Pannier, and J. Dubois, "Nature and nurture in language acquisition: anatomical and functional brain-imaging studies in infants," Trends Neurosci., vol. 29, no. 7, pp. 367–373, 2006.
[83] G. Dehaene-lambertz, G. Dehaene-lambertz, and S. Dehaene, "Functional Neuroimaging of Speech Perception in Infants," vol. 2013, no. 2002, 2014.
[84] W. O. Tatum, G. Rubboli, P. W. Kaplan, S. M. Mirsatari, K. Radhakrishnan, D. Gloss, M. Cook, and S. Beniczky, "Clinical Neurophysiology Clinical utility of EEG in diagnosing and monitoring epilepsy in adults," vol. 129, pp. 1056–1082, 2018.
[85] Oades, Robert D., A. L. H. X. A. N. D. R. A. DMITTMANN-BALCAR, and Dieter Zerbin. "Development and topography of auditory event-related potentials (ERPs): Mismatch and processing negativity in individuals 8–22 years of age." Psychophysiology 34.6 (1997): 677-693.
[86] A. D. Friederici, "Neurophysiological markers of early language acquisition: From syllables to sentences," Trends Cogn. Sci., vol. 9, no. 10, pp. 481–488, 2005.
[87] Kuhl, Patricia K. "Early language acquisition: cracking the speech code." Nature reviews neuroscience 5.11 (2004): 831-843.
[88] M. Cheour, T. Imada, S. Taulu, A. Ahonen, J. Salonen, and P. Kuhl, "Magnetoencephalography is feasible for infant assessment of auditory discrimination," Exp. Neurol., vol. 190, no. SUPPL. 1, pp. 44–51, 2004.
[89] T. Imada, Y. Zhang, M. Cheour, S. Taulu, A. Ahonen, and P. K. Kuhl, "Infant speech perception activates Broca's area: A developmental magnetoencephalography study," Neuroreport, vol. 17, no. 10, pp. 957–962, 2006.
[90] Aslin, Richard N., and Jacques Mehler. "Near-infrared spectroscopy for functional studies of brain activity in human infants: promise, prospects, and challenges." Journal of biomedical optics 10.1 (2005): 011009.
[91] Le Bihan, D., Mangin, J. F., Poupon, C., Clark, C. A., Pappata, S., Molko, N., & Chabriat, H. (2001). Diffusion tensor imaging: concepts and applications. Journal of Magnetic Resonance Imaging: An Official Journal of the International Society for Magnetic Resonance in Medicine, 13(4), 534-546.
[92] Valk, P. E., Delbeke, D., Bailey, D. L., Townsend, D. W., & Maisey, M. N. (Eds.). (2006). Positron emission tomography: clinical practice. Springer Science & Business Media.
[93] Friston, K. J., Holmes, A. P., Worsley, K. J., Poline, J. P., Frith, C. D., & Frackowiak, R. S. (1994). Statistical parametric maps in functional imaging: a general linear approach. Human brain mapping, 2(4), 189-210.
[94] Beckmann, C. F., Jenkinson, M., & Smith, S. M. (2003). General multilevel linear modeling for group analysis in FMRI. Neuroimage, 20(2), 1052-1063.

[95] Kuncheva, Ludmila I., and Juan J. Rodríguez. "Classifier ensembles for fMRI data analysis: an experiment." Magnetic resonance imaging 28.4 (2010): 583-593..

[96] Shattuck, David W., and Richard M. Leahy. "BrainSuite: an automated cortical surface identification tool." Medical image analysis 6.2 (2002): 129-142.

[97] Fedorov, A., Beichel, R., Kalpathy-Cramer, J., Finet, J., Fillion-Robin, J. C., Pujol, S., ... & Buatti, J. (2012). 3D Slicer as an image computing platform for the Quantitative Imaging Network. Magnetic resonance imaging, 30(9), 1323-1341.

[98] Cox, Robert W. "AFNI: software for analysis and visualization of functional magnetic resonance neuroimages." Computers and Biomedical research 29.3 (1996): 162-173.

[99] Whitfield-Gabrieli, Susan, and Alfonso Nieto-Castanon. "Conn: a functional connectivity toolbox for correlated and anticorrelated brain networks." Brain connectivity 2.3 (2012): 125-141.

[100] Lawhern, V. J., Solon, A. J., Waytowich, N. R., Gordon, S. M., Hung, C. P., & Lance, B. J. (2018). EEGNet: a compact convolutional neural network for EEG-based brain–computer interfaces. Journal of neural engineering, 15(5), 056013.

[101] Fischl, Bruce. "FreeSurfer." Neuroimage 62.2 (2012): 774-781. .

[102] Penny, W. D., Friston, K. J., Ashburner, J. T., Kiebel, S. J., & Nichols, T. E. (Eds.). (2011). Statistical parametric mapping: the analysis of functional brain images. Elsevier.

[103] Jenkinson, M., Beckmann, C. F., Behrens, T. E., Woolrich, M. W., & Smith, S. M. (2012). Fsl. Neuroimage, 62(2), 782-790.

[104] Kennedy, D. N., Haselgrove, C., Riehl, J., Preuss, N., & Buccigrossi, R. (2016). The NITRC image repository. NeuroImage, 124, 1069-1073.

[105] Andy, C. Y., & Masters, R. S. (2019). Improving motor skill acquisition through analogy in children with autism spectrum disorders. Psychology of Sport and Exercise, 41, 63-69.

[106] Ashby, F. G. (2019). Statistical analysis of fMRI data. MIT press.

[107] Jeay-Bizot, Lucas, Stella Berboth, and Carmen Morawetz. "Resting-State Connectivity and Emotion Regulation." MEi: CogSci Conference 2019, Ljubljana. 2019.

[108] Kristinsson, Sigfus, et al. "Machine learning-based multimodal prediction of language outcomes in chronic aphasia." Human brain mapping 42.6 (2021): 1682-1698.

[109] Saccà, Valeria, et al. "Aging effect on head motion: A Machine Learning study on resting state fMRI data." Journal of Neuroscience Methods 352 (2021): 109084.

[110] Meenakshi Khosla, Keith Jamison , Gia H Ngo , Amy Kuceyeski , Mert R Sabuncu “Machine learning in resting-state fMRI analysis” 2019. Epub 2019 Dec;64:101-121

[111] Jaworska, Natalia, et al. "Leveraging machine learning approaches for predicting antidepressant treatment response using electroencephalography (EEG) and clinical data." Frontiers in psychiatry 9 (2019): 768.

[112] Kora, Padmavathi, et al. "EEG based Interpretation of Human Brain activity during Yoga and Meditation using Machine Learning: A systematic review." Complementary Therapies in Clinical Practice (2021): 101329.

[113] Hyder, R., Højlund, A., Jensen, M., Østergaard, K., & Shtyrov, Y. (2020). “Objective assessment of automatic language comprehension mechanisms in the brain: Novel E/MEG paradigm.” Psychophysiology, 57(5), e13543.

[114] Lee, D. A., Lee, H. J., Kim, H. C., & Park, K. M. (2021). “Application of machine learning analysis based on diffusion tensor imaging to identify REM sleep behavior disorder”. Sleep and Breathing, 1-8.

[115] Saikia, M. J., Kuanar, S., Borthakur, D., Vinti, M., & Tendhar, T. (2021, March). “A machine learning approach to classify working memory load from optical neuroimaging data”. In Optical Techniques in Neurosurgery, Neurophotonics, and Optogenetics (Vol. 11629, p. 116292L). International Society for Optics and Photonics.