

Brain Plasticity in the Light of the Critical Period

The key to human learning lies in the plasticity of the brain which is the brain's ability to acquire new functions resulting in the change in its neural structuring. Among the most demanding brain functions, language learning is researched with the highest urgency and intensity, relating to both childhood and adulthood. Brain plasticity, as any other physical conditions, is influenced by age. In applied linguistics it is called the critical period: an interval at which language acquisition takes place without effort, and is usually characterized by the achievement of high level of proficiency Penfield and Roberts (1959). They argued that language acquisition is most efficient before age 9 when the brain turns inflexible. Lenneberg, 1967 insisted that during these years the brain completes its process of lateralization of language functions to its left hemisphere, ending by the onset of puberty. Lamendella (1977) found that language acquisition is much easier in early childhood but not at all impossible later in life. He introduced the term of sensitive period to gain validity to his claim.

In this paper I will examine the connection between brain plasticity, the critical period and memory, including a thorough examination of the neurological background and processes in the brain during language learning on purpose to promote further research on even more success in adult language learning. The neural responsiveness of the brain is quick, aided by

the neurological condition of mediation (Jacobs, 1988), which refers to the cover of the axon endings in the brain with myelin, a substance more effectively conducting neural impulses between neurons, thus creating new, thicker synapses capable of transmission at intense acceleration. The brain in this stage, regarding language learning capacity, performs tasks of perceptual (phonetic distinction), and conceptual (word learning) with precision, not taking very long from birth to acquire these skills (Pearson, 1995, Werker et al. 2009, Vihman 1985, (Bosch & Sebastián-Gallés 2001). The high score achieved on tests in which the babies were tried to recognize objects and identify them correctly in both of their mother tongues showed the acquired knowledge of infant experimental subjects of phonetic distinction and vocabulary did not interfere even in test situations. As Werker 2009 defines, the two components of a successful language acquisition is the person's ability to separate and discriminate between the two acquired languages. Bilingual infants at the earliest stage of vocabulary usage can handle the challenge of translation of words in both languages with the same meaning as evidence for assumption that the languages in the bilingual brain, although are stored in the same neural bounds, are applied without interference between one another (Pearson, 1995). Bosch & Sebastián-Gallés 2001, tested phonetic distinction processes in four-month-old bilinguals following a familiarization period in either one language or the other. The test used auditory stimuli to which the subjects responded by orientation to light from the direction of the positively identified segments. Results displayed the effect that children were looking longer in the direction of the non-familiarized sounds of the two language samples, revealing similar abilities as those of monolinguals of their age. In the

Language preferences by contrast, monolinguals and bilinguals showed different behavioral patterns. Monolinguals reacted more rapidly to native language input than bilinguals, who showed interest in responding to the non-familiarized codes (Bosch & Sebastián-Gallés 1997; Dehaene-Lambertz & Houston 1998). A possible reason for this is that the bilingual children delay to react to language samples until they recognize the current native language in use, just as it is noted in older children growing up bilingual (Kovács & Mehler 2009). Newborns' language discrimination abilities were tested in groups of bilingual English-Filipino and monolingual English subjects whose responses to different linguistic patterns was measured by the strength and frequency of their sucking rate on a pacifier attached to a sensor-equipped computer. They found that monolingual English babies sucked more actively on the pacifier when they heard the sound and rhythm of their only native language, while bilinguals showed no change in their behavior at any of the stimuli. One explanation to this comes from the theory that babies in the last months of pregnancy learn to recognize the characteristics of their native languages and the familiarity they thus gain orients them to the preference of that language (Moon et al.(1996) This supports the neurological background of learning and memory based on repetition and practice until the involved neurons create connections strong enough to make it permanently imbedded in the hippocampus from where it can be retrieved as a memory of permanent storage. The subjects even in the womb received enough input to help forming neural patterns and were able to recognize the familiar sounds when they encountered them as they retrieved them from their memory systems. However, the early sensitivity to different perceptual details ceases by the

age of the eighth month of life resulting in the storage of details relevant for the current environmental requirements and the decrease in the capture of those of lower salience (Werker & Tees 1999; Pascalis et al. 2002; Werker et al. 2009). . Visual language recognition studies conducted by 4 6 and 8 month old monolingual English and bilingual English children showed that in the two younger periods babies were able to discriminate between the two languages just by watching silent-talking presenters. In the eighth month, monolingual babies lost the ability to distinguish the non-familiarized patterns. The ongoing tests on monolingual and bilingual phonetic distinction revealed that in case of Spanish-Catalan bilinguals and Spanish monolinguals, bilingual children at the eighth month also seem to lose their ability to distinguish linguistic categories before they succeed in discrimination again at the 12th month (Bosch & Sebastián-Gallés 2003). Other research showed that monolingual children at the age of seven months are able to discriminate phonetic patterns occurring in their native language from those that are not its constituents, but they prefer listening to the familiarized samples of their mother tongues (Jusczyk & Aslant 1995; Jusczyk 1997). Their study on English-French bilinguals and English monolinguals in a mispronunciation perception test in which the researchers used minimal pair distinction tasks (cup-top) concluded that children at this period are not only able to recognize and separate initial consonants of words, but that they are able to distinguish different familiar and non-familiar word forms as well (Jusczyk & Aslant 1995). The developmental phase at the eleventh month exemplified that monolingual French children listened more to frequently heard words and rejected the non-familiar ones. They also listened to minimal pairs such as 'contour', 'boiture'

(Halle & Boysson-Bardies 1996). This suggests that children may be able to encode phonetic data but it is necessary for them to reach a higher level of maturity to insert and maintain the non-familiarized entries in their brains.

Another key property of language lies in its complexity both in terms of production and in the sense of comprehension. Its multiple facets are represented in the brain in various ways and their simultaneous functioning requires parallel processes that demand specialization in the brain. The lateralization of language to the left hemisphere of the brain is the result of the evolution of the language itself. Catani et.al. (2007) conducted a research in order to prove the connection between asymmetric brain organization and cognitive functioning known as lateralization. It is the asymmetrical distribution of cognitive functions between the two hemispheres. The most indicative specialization exemplifying the phenomenon is the localization of language. The language pathway on the left hemisphere consisting of Broca's and Wernicke's areas linked by the arcuate fasciculus is responsible for language production and processing. The right hemisphere in contrast, aids language comprehension by associating semantic relationship between words along with word learning, and retrieval. The asymmetry and cognitive function connection give a reason to the distinct operations and perhaps to the process of late bilingual language processing aided more with additional devices. It also proves the plasticity of the brain concerning bilingual language processing occurring first with right hemispheric dominance and continuously orienting leftward in proportion with proficiency. Evidence for language localization is available through the study of lesions, structural and anatomical analyses. In right-handed patients with

language deficits, the lesion almost in all cases affects the left hemisphere. Regarding structural asymmetry, Geschwind and Levitsky found a difference in the size of the planum temporale, the area of the temporal lobe in which Wernicke's territory is localized. Catani et.al. (2007) conducted a diffusion tensor MRI pathway reconstruction examination which is the analysis of the trajectory of axons by measuring the diffusivity of water along various directions and trace their pathways to diffusions of the least hindrance parallel to the dominant fiber thus forming pathways. The procedure is only suitable for detecting large scale pathways. The technique revealed three important parts of the language pathway. There is a direct pathway connecting Wernicke's region in the left temporal lobe with the arcuate fasciculus the Broca area in the left frontal lobe. Two indirect segments are also present with an anterior segment linking Broca's territory with the inferior parietal lobe known as Geschwind's territory. The third, posterior pathway connects Geschwind's territory with Wernicke's region these three pathways together constitute the Perisylvian language pathways. This organization allows very flexible parallel processing. They found as a result of the DTMRI study the Perisylvian language pathway being an asymmetric representation with very distinct connection pattern in the left hemisphere in comparison with the right. The analysis revealed indirect pathways both in the left and right hemispheres with one anterior indirect segment and one posterior indirect segment. Pathways connecting frontal and temporal lobes on the right hemisphere the scientists were not able to reconstruct. By contrast, the pathways directly connecting the frontal and temporal lobes in the right hemisphere are clearly visible. These data were acquired in the DTMRI examination of 40 subjects by

creating maps of each segment showing overlaps with segment mappings of each subject. The segment overlap maps confirmed the asymmetrical distribution of the direct segment and the symmetrical distribution of the anterior indirect and the posterior indirect segments. This confirms our knowledge of the inter-hemispheric distribution of language pathways.

Frederica et al. 2002 showed in their study the effects of the critical period on brain structural processing's during language learning by teaching artificial linguistic samples to adult subjects. By using ERP techniques, they showed that adult language learners gaining proficiency in the artificial language present similar brain activations as native speakers do when processing a natural language. This supports the theory that both L1 and L2 are processed by the same neural devices, with the difference only in linguistic computations influenced by age of acquisition, level of proficiency, and exposure intensity to language. The L2 computations call adjacent brain areas to help the original L1 storage area of the left perisylvian devices in operation including temporal, frontal, and parietal regions in collaboration with subcortical areas. Brain imaging studies revealed that solving grammatical task bilinguals in both L1 and L2 used as well, the basal ganglia region adjacent to Broca's area originally responsible for the execution of such activities. Additional L2 activation was even more evident in extending to further regions in case of bilinguals of low proficiency or late acquisition. Earlier evidence to age-dependent grammar acquisition shows that children are born with an innate ability to learn any type of grammar. This is the theory of the Universal Grammar established by Chomsky, 1965, claiming that in proportion with aging, children lose their capacity to adapt to different grammatical systems. Lexical acquisition by contrast, does

not fall victim to the critical period, but serves as a way to enhance brain plasticity since it depends on proficiency influenced by usage and exposure. Psycholinguistic evidence indicates that in early L2 acquisition, meanings of L2 lexicon are mediated to access by L1 lexical items; as L2 proficiency increases, the dependence on L1 decreases. The Convergence hypothesis by Green (2006) argues that the closer one gets to L2 proficiency, the more resemblance he displays to L1 performance. It also claims that the acquisition of L2 arises in the context of an already specified, or partially specified, system, and that L2 will receive convergent neural representation within the representations of the language learned as L1. Numerous research concluded that L2 subjects with near-native proficiency showed the same left hemispheric activation during word, or sentence production, and comprehension tasks as native speakers, not regarding syntax, phonology, or orthography, whereas low-mastery bilinguals displayed additional prefrontal brain activation at the execution of the challenges. On the basis of these results the assumption forms, that word generation is another exercise for achieving higher extent in brain plasticity.

The experiment conducted by Frederica et al. 2002 revealed that highly trained participants in an artificial language at the ERP test showed early automatic and late controlled syntactic processes while untrained subjects did not. Their findings also were identical in the agreement that teaching small chunks of grammar at a time can achieve its familiarization in the adult brain so effectively that its processing will resemble the capacities of a native speaker in a natural grammar task situation. This suggests that language acquisition itself is not, but sentence production is effected by the critical period in

accordance with phonemic distinction mentioned above. In syntax violation testing with native speaker showed a characteristic biphasic response in the ERP consisting of an early negativity and a late positivity. It was often noticeable in the left anterior areas but sometimes manifested itself in the bilateral frontocentral regions. To the latter phenomenon, no written documentation has yet served with explanation. The early negativity 100-200 ms after encountering the violating word tells about the interruption of a highly automatic process. The second component of syntax: late positivity occurred 600 ms after the syntactic anomaly. The p600 component is associated with the reanalysis and repair of the incorrect segment. Repair processes after a syntactic violation in native speakers appear in a centroparietal positivity p600, syntactic reanalysis appears front central p600, while late L2 learners instead of showing the early negativity show reduced p600 in response to syntactic violation even after several years of L2 practice. They show straight posterior, right hemispheric negativity in reaction to the faulty segment suggesting the presence of complementary conceptual processes. These findings prove the low automation of sentence processing difference with L2 learners subjected to L2 after puberty as opposed to those of native speakers. However, the small grammar chunk processing in the test showed that grammar could be fully adopted by adults even later in life. Researchers insured that the subjects became masters of the miniature language, thus proved that high degree of proficiency develops the involved brain mechanisms to resemble those of native speakers even when the L2 is acquired after the offset of the critical period. In the duration of the experiment they agreed on three generally applicable findings: that extensive vocabulary feed delays access to syntactic word categories

by which syntactic structures form. Another obstacle in reaching proficiency is the difference of the syntactic systems between the two languages. Phonological patterns such as prosody influence the syntactic processing of more complex structures. To avoid difficulties, they examined syntax violation response processing of a simple and controlled artificial grammar to examine the validity of the critical period hypothesis and the less is more hypotheses which argue that L2 processing can be just as proficient as that of L1 speakers if the grammar meets the learner in small chunks. From this theory the scientists derived the assumption that language processing is more the product of proficiency than of age. The proficient users of the artificial language reacting to its syntax violation showed the following ERP patterns. Syntax violation resulted in early frontocentral negativity between 100-200 ms, after which appeared a more posterior effect between 200-350 ms, then presented a long lasting, extensive positivity starting frontocentrally between 350-500 ms, and eventually revealed centroparietal distribution between 650-900 ms. The early negativity, as a response to syntax violation, was most noticeable in the anterior electrode positions, and the late positive P600 component was typically localized at the centroparietal region for the grammatical violation. The qualities of the two components presented syntax parsing just as automatic as it in case of a native speaker of a natural language would have appeared. The posterior negativity showed phonological mismatching negativity observed for phonological distinction of the target word and between the expected items. This later posterior negativity without the anterior negativity suggests conceptual accompanying aid. This means that although automation is present in the

test results of the proficient users of the artificial language, some more devices remain to help language processing.

Since the highest degree of brain plasticity is induced by word learning, I give some more of the details as well as of the brain regions playing a role in the process. The two stages of word learning begins in a rapid initial phase supported by medial temporal and hippocampal brain areas (center for episodic memory systems), and in a slower neocortical (center for long term memory) learning achieved by offline consolidation of previously acquired words (McClelland et al. 1995). This is the complementary learning systems model which suggests that in lexical learning the rapid initial familiarization of the new item is followed by a slow lexical consolidation stage. This model presents learning systems that are closely related to other types of memory such as the system of procedural and declarative memory (Squire 1992), episodic-semantic memory (Tulving 1972). The difference between the two network connections is that the procedural and semantic memory ties store learned information in independent wide-spread codes which have only little overlap between distinct neural regions. The cls model, by contrast, indicates that the two network systems are inter-related and are available for mediation by transfer consolidation mechanisms. A stable cortical consolidation is the end product of the excessive amounts of repetition of the new concept followed by consolidation processes like sleep, by which the newly acquired systems are segregated from the specific occurrences in items stored in the episodic memory sections. Norman et al. (2005) argue that sleep provides opportunity for offline consolidation processes like hippocampal replay, restructuring, and restrengthening of memories that play a role in

neocortical training. The subsequent sleep-wake phases are essential in neural network learning as they induce error-driven learning which is the constant replaying of the newly acquired information in the REM phase and the correction of the errors it makes during the process of recollection (O'Reilly 1996). Fenn et al. (2003) in their study proved that perceptual and procedural non-declarative production improve by over-night sleep associating the improvement in the interpretation of synthesized speech with the time of the day, as well as the current stage of alertness. They found that tasks performed with high degree of excellence in the morning end in a lower degree of success in the evening, suggesting that the time awake was detrimental to the observed skill; the change caused during an over-night sleep phase was considered to execute a healing effect on performance. The consolidation of declarative memories was found to be the most efficient in the non-REM (early sleep) phase Plihal & Born (1997, in an experiment at which the subjects were tested on associate-pair-recall tasks. Studies showed that the task prior to sleep had neural influence on the non-REM phase brain activation, examined by EEG measurements of neural activity during this phase revealed short bursts of intense firing related to declarative learning. The Distributed Cohort Model, Gaskell & Marslin-Wilson 1997 presents functional and anatomical organization of the neocortical areas involved in the recognition of spoken words. The model focuses on the perception and identification of words, including the efficient use of incoming input in the speech signal, variation in the perceptual form of speech, competition between phonologically similar lexical items. The model features a recurrent network in which sequences of acoustic sounds arrive at the stage of lexical representation via a neural network which processes the

encoding of incoming information on spectro-temporal feature representation in pre-auditory regions in the superior temporal plane (Patterson et al. 1995; Chi et al. 2005). According to the model, the brain operates neural pathways in an orderly sequence in the processing of extraction of linguistic patterns under their supervision from the ongoing input (speech). This means that for the phonetic information to walk its route in memory to lexical knowledge, it takes short term storages so that sequences could be embedded over time and be discriminated. Thus, the neural pathways process both the current input and that of what had been previously contracted through the auditory channels. For these sequences to remain in memory, more devices are called into operation from more brain regions to make computations. These neuroanatomical connections provide a transit memory storage: auditory echoic memory for previously heard input, involving the anterior regions of the superior temporal gyrus (Nussbaum et al. 2005; Price et al. 2005; Davis & Johnsrude 2007). Since the echoic memory provided by the anterior temporal regions plays a crucial part in sentence comprehension (Mattys 1997), brain imaging tests of related tasks prefer the examination of these regions (Scott et al. 2000; Davis & Johnsrude 2003; Humphries et al. 2005). The model also displays a process of the separation of phonological features from the meaning of a lexical item from its phonological representation involving two separate pathways. Psycholinguistic tasks examining the lexical and phonological outputs by the repetition of words and pseudo words and the ways of access to them show keen interest in the operation and connection of both the dorsal and ventral pathways. The dorsal and ventral pathways are two auditory language routes in the brain via which phonological and conceptual information

from auditory input are processed (Hickok & Poeppel 2004, 2007; Davis & Johnsruide 2007). The brain regions on the route of the ventral pathway are the posterior auditory stream, the superior temporal gyrus, and the inferior parietal lobe, in charge of handling word meaning processes including sensory representation of new words and phonological short term memory (Scott & Johnsruide 2003; Hickok & Poeppel 2004, 2007). The dorsal pathway carrying out access of phonemic representations from spoken stimuli involve brain regions of the posterior inferior temporal and fusiform gyri (Hickok & Poeppel 2004, 2007). Taking into consideration the requirements of memory needs, phonological and semantic perception devices, scientists conclude that the brain regions involved in lexical acquisition are the superior temporal gyrus (phonological representation regions), lateral temporal lobe (word meaning and auditory connections), and memory systems in the medial temporal lobe (McClelland et al. 1995; O'Reilly & Norman 2002), hippocampus and the neocortical network: supporting the identification of meaning. On the basis of the neocortical route's involvement following the hippocampal route in lexical item learning we can assume, that their acquisition go through a surface and a deep familiarization process. One explanation to word learning thus assumes a time delay in the hippocampal recognition processes until the information makes its way into the neocortical route for support at which recognition processes would speed up and consolidate to be able to be selected together with words of already existing meanings. Word learning on the basis of the back propagation model which is the two-way processing of learned information says that learning takes place by the forward propagation of the training patterns through the neural network for the purpose of generation of the

propagation's output activation. This means the repetitive practice with the newly acquired information in the form of input, while in the reverse mode the output activation is used through the neural network to generate via the training pattern the hidden neural activity (Rinehart et al. 1986) takes place by the formation of weight connections between the unit and the network which are adjusted in the neocortical route via multiple representations allowing gradual learning as well as the recognition of the familiar words and the familiarization of new items. The acquisition of new words does not result in the loss of words of already existing knowledge because the acquisition proceeds by the network connections described above while the neocortical regions help the identification of already acquired words in parallel, thus setting the two processes on to two pathways: the hippocampal and the neocortical routes. This isolation of the hippocampal route and the neocortical route might be the reason for the difficulty in the retrieval of newly acquired items. If the hippocampal route is weighted too highly meaning the overload of information, in this case it refers to the exposition to too many new words to learn in a short period of time, the interference with the neocortical route results in recognition failure of already stored words. The weak weighting of the route causes loss in the extraction of the new word.

The storage of learned knowledge in the hippocampus relies more on the synaptic plasticity of the brain. The synaptic plasticity in memory hypothesis claims that during learning spatio-temporal neural activities representing events cause long-lasting changes in the strength in the synaptic connections in the brain. Later reactivation of these connections triggers cell firing turns that constitute the experience of memory and results in changes in

behavior or expression induced by these turns (Morris et al. 2003). In the cases of the hippocampal and neocortical memory systems of lexical storages we have concluded that these require different brain regions with their relating synaptic connections. A more advanced version of the synaptic plasticity in memory claims that different memory systems need to perform mechanisms according to their unique features. Activity-dependent synaptic plasticity is induced at appropriate synapses during memory formation, and is both necessary and sufficient for the information storage underlying the type of memory mediated by the brain area in which that plasticity is observed (Morris et al. 2003).

Conclusions

Beyond the purpose of finding evidence for brain plasticity at any age in life especially in terms of second language acquisition, studies have lead me to draw assumptions regarding the factors behind problems in adult language learning. The experiment conducted by Frederica and her colleagues proved that the tasks most vulnerable to the critical period are more advantageous to acquire in small portions later in life. Although it is an experimental study and the technique was not applied anywhere outside the laboratory, it is worth paying attention to these findings for further application as part of methodology update. Besides the novelties, the qualities of memory formation and synaptic decay remains as a great influence on learning. The decay of synaptic connections, if not in intensive use, or only rarely weighted lose their strength and the knowledge they carry, so the importance of constant exercise also essential for successful language acquisition. A third component in the process

is motivation, a more psychological than neurological factor which also manifests itself in the neural structuring if it promotes adequate exercising. Among the human factors of adult ll learning difficulty anxiety, willingness to communicate (MacIntyre and Charos 1996) and motivational constraints (Gardner 1997) have a high frequency of occurrence. Studies with children indicate that successful language acquisition relies, and builds upon early phonemic distinctions corresponding to word boundary recognition, and word learning. In adulthood the recognition exercising of these two components require the complementary task of grammar rules to be acquired in manageable portions Frederica (2002). As I used memory consolidation, and grammar learning capacity improvement to support the theory on adult brain plasticity, I gained a deeper understanding of the significance of additional brain regions assisting language production and comprehension in late bilinguals. In order to advance in developing methods in language learning, there is a need for further research on the brains mechanisms of both early and late bilingual neural processing including the exact function of the assisting brain regions supporting late bilingual language functioning.

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