

幼少期の第一、第二言語レキシコン処理と記憶 における生物学的証拠に関する検証

Examination of Biological Evidence of Early First and Second Language Lexical Processing and Memory

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Abstract

This study examines the brain's biological evidence in L1 and L2 lexical acquisition and memory. By developing the theory of absence of vocabulary labels suggested by Lenneberg, the study clarified the relationship between language acquisition and biological states of brain areas and size according to latest observation data. To raise accuracy and to reconstruct the problem based on previous studies, the study emphasized the following five new points. They are; brain areas related to language information, its compatibility and parallel relations with acquisition, correlations with already learnt L1, early L2 and late L2 learners' biological and neurological limitations, and comparisons of collateral effects. Significant findings include divergence in general memory mechanism and linguistic memory mechanism, temporal dynamics of linguistic memory, increase in brain size, acquisitional stabilization and development through reinforcement rather than augmentation, and dissimilarity in language processing mechanisms between early and late L2 learners. Linguistic information constructed from infancy to childhood is based on phonological binding. Linguistic knowledge before the critical period of age 12 to 13 is at a developmental stage in grammatical and semantic web of cognizance, and as information, processing is proven to be different from grammatical processing, in terms of neurological dimension. Also, the existence of the web of meaning is seen to be related to the reason for the existence of L2 critical period.

1. Statement of Research Question

The purpose of this article is to gain an extensive delineation of second language lexical storage structures in the stages of neurological formations of children's brains. A five-step approach for this theme will be to focus on the following; 1. Areas and their size in the brain where lexical storage occur, 2. Access to language and how it occurs in relation to the first language, 3. The incremental linguistic build-up, or accumulation as acquisition advances, 4. Biological constraints and/or sub-effects, during, or resulting from early L2 accumulation, and 5. How the brain develops and what happens to L2 lexicons as maturation progresses. The above five steps take into further consideration the following ancillary questions; 1. Is there a difference in the process between L1 word-concept development and that of L2? 2. If L1 and L2 development occurs simultaneously for young children, does the L1 and L2 storage system differ from those of older learners (11 to 12 years old)? 3. Do the two groups, as a result, develop different systems of mental lexicon storage? The main focus will be on biology of language development; namely within that of the brain; internal brain areas and regions pertaining to linguistic function and transformations over the course of growth during childhood where significant developments and changes are assumed to occur. Closer examination will be on differences in outcomes according to age of acquisition as supported by biological evidence. Rather than focusing on experimental or theoretical investigations into the cognitive or syntactical- semantic aspects in bilingual development, this paper will look at the evidential and biologically proven dimensions of neurological aspects in bilingual development. Gaining an initial foothold into biological data will enable the acquisition of stronger evidence for further related studies from other areas.

2. Review of Literature

Neuro-imaging studies have specified¹ biological developmental patterns in the brain. Works on early neurological development of L1 and L2 areas in the brain focus on neuroscientific techniques such as Electroencephalography (EEG), Event-related Potentials (ERPs), Magnetoencephalography (MEG), functional Magnetic Resonance Imaging (fMRI) and/or Near-Infrared Spectroscopy (NIRS). EEG and ERP measure electrical field changes and has outstanding temporal resolution. MEG measures magnetic field changes, and has outstanding temporal and spatial resolution, fMRI and NIRS measure hemodynamic changes (changes in blood flow) and have excellent (fMRI) and good (NIRS) spatial resolution.² The electrical-field and hemodynamic changes are a strong indicator of physiochemical reactions taking place in the brain, through means of synapse-receptor and endogenous-reactions.

Furthermore, neuroscience on early language learning suggest that multiple brain systems are at work in the human language faculty.³ Over the years, relationship between language acquisition and brain development have been reported in detail.⁴ This paper will narrow its scope in viewing language acquisition and its relation to brain development by focusing on early L2 learners and their L1 and L2 lexical processing in particular.

3. Areas of Lexical Storage in the Brain

When aligned flatly on what we call a brain-map, the positions of each functioning unit within the brain becomes clearer. The front part of the brain, known as the Olfactory front, houses executive control at the front top on both left and right hemisphere. It is connected to Broca's area that seats the loop and also is where rehearsal takes place. Down below, near the center is the storage area. Temporary storage of the auditory side is located near the Occipital back, while Wernicke's area is on the left. Amygdala, which processes emotions is at the center while the hippocampus, connected from the storage center, is close to the non-mesial region near the center.

Lexical storage is related to learning and memory, and the brain area concerning short-term memory includes the hippocampus and its surrounding areas, working memory; the prefrontal cortex and long term memory; the cerebral cortex. A classical operant conditioning reaction takes place in the cerebellum. During processing of word information, the executive control mechanism of the brain orders attention injunctions, dispersion, and substitution. In the phonological loop, the left frontal lobe is used for practice, while temporary memory/ information storage is made on the left parietal lobe. Broca's area induces speech production, while Wernicke's area enables understanding. Thus, lexical storage, most closely related to memory, is closely linked to the faculty of the hippocampus.

Much evidence has pointed to the dominance of the left hemisphere in language processing. To be specific, processing of written words is not an innate function anatomically programmed at time of birth. The brain is said to be rewired to cognitively recognize shapes that form letters and words.⁵ On the contrary, processing phonetic sounds uses another brain area, that involves executive control, the phonological loop, Broca's area, Wernicke's area, and the hippocampus.⁶ Lateralization of the brain areas is often signified by multiple sources (de Groot 2011, Hernandez, 2013, Sakai, 2005). Some evidence show that the right hemisphere also comes in play when it comes to metaphoric, pragmatic, and irony production.⁷ Both Broca's area and Wernicke's area have been pointed out to be contributing to language processing.⁸ Putamen and globus pallidus are also occasionally involved.⁹

As for L2, differential lateralization evidence is scarce, and some data even show that there are no specific L2 areas in the brain. Although L2 involves the temporal lobe,

language processing seems to be widely distributed across the cerebral cortex. However, for bilinguals, a relationship with areas concerning inhibitory control has been indicated. Also, left DLPFC, ACC, and caudate nucleus are activated among bilinguals.¹⁰ An additionally noteworthy point is that general executive control mechanism supported by a subserving network of brain structures is significant for bilinguals.

Moreover, for bilingual control, different neural networks (neural switch and non-switch)¹¹ seem to be at work. Depending on whether the learner is an early L2 or late L2 learner, subsequent neural organizations differ. Also, linguistic and translational areas are stated to be neuro-functionally separate.¹² Looking more closely at neurobiological development related to the language learning process and its sub-divisional areas according to linguistic functions, some findings including the following have arisen.

Findings indicated that lexical knowledge is classified into explicit declarative memory which takes place primarily in the temporal lobe in Wernicke's area, and grammar, in the procedural memory, a memory on how to do things, which is mostly sustained by left frontal structures and basal ganglia, including Broca's area.¹³ Foundational linguistic ability belongs to declarative memory, including cultural information, and is stored in the temporal lobe and the thalamus. As for languages such as Japanese where Chinese characters, Kanji, is involved, it is found that occipito-temporal areas of right hemisphere occurs with phonological processing.¹⁴ The closer the periods of L1 and L2 acquisition, the more similar the lateralization pattern.¹⁵ Also, monolinguals are seen to be moderately left-sphere dominant compared to bilinguals.¹⁶

The age of L2 exposure has much to do with bilingual cerebral language organization. Also, age of acquisition has a lot to do with bilingual cerebral organization of grammar.¹⁷ For both L1 and L2, the emphasis on change of neural structure has not been on their differences in location, but of strength.¹⁸ This could also be attributed to social efforts that could enhance greater learning among infants. There has been repeated evidence that no L2-specific brain regions exist.¹⁹ The only overt difference is that of strength of activation.

Also, observations of involvement of different neural networks have been reported.²⁰ As the sensitive period is said to occur before 7 years of age, phonetic development occurs early in life, and therefore early years of exposure leads to settlement of neural circuitry. Neural commitment, including neural circuitry and overall architecture develops early in infancy for the purpose of speech detection.

4. Access to Language in Its Relation to L1

There are few papers indicating differential lateralization among L1 and L2 processing. In L1, the temporal lobe in the Wernicke's area is activated more than for L2.²¹ While L1 word production is automatic, the weaker L2 involves many controlled

processing resources.²² L2 requires more effort and is inefficient in composition process. Early bilinguals' L1 is said to be more bilaterally localized.²³ Again, it is the strength of the activation, not the location, that is seen as characteristic of both L1 and L2 regions.²⁴

As with access to language, major linguistic factors include phonology and lexico-semantics at the word level and syntax and sentence comprehension at the discourse level.²⁵ Phonetic learning, especially, which is shaped as phonetic units through social context, occurs early on.²⁶ Further studies by Sakai have revealed that for L1 with age of acquisition before 6 years of age, and L2 with age of acquisition after 7 years of age, there was a difference in the activation of cortical areas. Another case showed that in sentence processing tasks for the above subjects, they showed common neural substrate activation. Another study showed that in fMRI, L2 showed dominant IFG activation in grammatical processing than for L1. Even if age of acquisition are the same, the degree of exposure to a language influences IFG activation (Sakai 2005). Modulation was different according to age and task for left frontal and extrastriate region, but results proved different according to task content demands, so the relations are still unclear (Sakai, 2005).

5. Linguistic Build Up in Terms of Advancement in Acquisition and Accumulation

First, Lenneberg has commented on the impossibility of a word or lexico-image itself to be stored in the brain as visual or audio-labels. He has hypothesized that it is difficult to imagine 'indications' or perceived 'images' of language depending solely on horizontal organizations within the cortex (Lenneberg, 1974). These are better characterized as being formed from temporal interactional patterns within cortical structure and subcortical structures, and this matches the results of previous experiments. Evidence of breakdown of unified connectivity from cortical lesion does not exist. It is unclear what connects at the time of language learning. Words are not labels for objects but are part of a process of conceptual function.

Within any part of the brain, there is no evidence that basic behavioral fragments (i.e. perceptual images limited to auditory or visual perception) that are thereafter amalgamated to form a more audio-visual perceptual connectivity, is stored. Pattern recognition may be injured from some combinations of lesions, but such lesions are not seen as disassembled or divided perceptual images of connectivity. Furthermore, audio-visual perceptual connectivity is not recognized to be related to linguistic abilities.²⁷

Since Lenneberg's hypotheses, recent discoveries using neuro-imaging techniques have elaborately improved. Although his main thesis of the absence of a concrete 'word-image' within the neural network has not been disproved, multiple brain systems came to be known to underlie human language accumulative faculty. The first is that the development of the corpus callosum is affected during language learning.²⁸ The second is

that auditory phonological processing is seen to occur in the posterior superior temporal gyrus.²⁹ The third point is that lexical-semantic processing is seen from the activation of the left extra-sylvian temporal region, and additional regions are reported to be activated for the second and third points.³⁰ During phonological decision, observance of bilateral STG activation is reported.

As for neurological traits observed among language learners, some new findings have been reported to compliment Lenneberg's hypothesis. First, neural organization comes to differ among early and late language learners. Neural signature of phonetic levels are seen from an earlier stage. Exposure to L1 during the first year of infancy influences the neural circuitry.³¹ Also, during the early years of language acquisition, a combination, not only of neuro-cognitive skills but also of computational, cognitive, and social skills renders a powerful learning mechanism.³² The timing where neural circuitry and overall architecture develops is during early infancy, where phonetic and prosodic patterns are internalized.³³ The brain size is characterized by massive increase during its first years.

As with the units concerning word detection in a BSN (Bilingual Single Network) Model, the number of units is found to be the following: Semantic Feature Units (120 Units) Language Coding Units (4 or 8 units per language) Hidden Units (number varies from 40 to 80) Orthographic Units (30 Units) and Language Coding Units (4 or 8 Units per language).³⁴ All these features are essential constituents for the three stages of language processing; coding, storage, and retrieval.

While both children and adults have capacities for language learning, the brain utilizes different knowledge base in language learning among adults and children. For adults, the brain is reliant on declarative knowledge alone during a language learning process, whilst for children, the brain is reliant on both declarative and procedural knowledge.³⁵ When it comes to two languages, it becomes more complex. Lexical items must be organized with grammatical features within a language system. For children, the method in which to systematically acquire language begins with 1. specifying phonemes 2. matching 3. creating lexemes, which is then 4. codified to grammar, and finally 5. made into sentences.³⁶ There are three conditions that are relevant in the speaking of language. The first point is linguistic and lexical complexity, which include diversity of grammatical structure and variety of vocabulary. The second point is cognitive processing, which necessarily requires perfection, articulation, systemization, and informational content. The third point is conversation process that involves time constraint among mutual relations, speed, and type of utterance.

L1 acquisition and processing firstly occurs through functions of coding, storage, and retrieval in the brain while the brain processes phonological information into speech comprehension in the brain. 1. Coding- During coding, phonemes, as phonological information, enter the phonological loop, involved in temporary storage and rehearsal, and are transferred to Wernicke's area as lexemes, while constant exchange of information occur between phonemes and lexemes and speech comprehension is made. 2. Storage-

Phonemes are then stored as lemmas and lexemes in the non-mesial region of the brain. 3. Retrieval- As for retrieval, records of words as lexemes and tags in the non-mesial region and phonemes in the Wernicke's area, are both sent to the Broca's area, as lexemes and phonemes, and are rehearsed sub-vocally in the phonological loop.³⁷

During the acquisition of new vocabulary, certain aspects of form and meaning play a role. From an early stage, form-meaning relations must be constructed. During the acquisition of new vocabulary, a definitive role is played by working memory. During the processing of phonemes and lexemes, three elements, attention, sense and emotion, also play important roles. Attention is directed to the word before it is made audible. In sense, information is provided to the pituitary gland. In emotion, the amygdala plays a crucial role in neurological processing.³⁸ According to Skehan (2009), impoverishment of phonological memory leads to a disadvantage in acquiring new language.

Age of acquisition may be confounded with language proficiency. There is certainly a linear relationship between age and phonological processing.³⁹ It is supported by early ability to separate speech sound systems followed by early ability to learn 2 grammatical systems. There is a hypothesis called "phonological bootstrapping" where aspects of grammar can be found in underlying phonological and prosodic structures.⁴⁰

Language learned later will be separated into two memory systems, which perform a different role than L1. Lexical information is processed in the declarative memory, whereas grammatical information utilizes procedural memory. Bilinguals will execute sentence production correctly even when two grammar systems conflict.⁴¹ This is because later exposure to language may impair the ability of procedural memory to learn and compute aspects of grammar.⁴² Neurological structures that shape cognitive process that later shape neural configurations are largely determined by the time of critical period, but the precise acquisition timing of phonetic, lexical, and syntactic levels varies among each individual level,⁴³ so that it could not be recorded at this point. There are also social factors linked to fundamental learning mechanisms such as the mirror-system, which occurs at different levels in different environments.⁴⁴ Therefore L2 abilities themselves do not follow fixed steps but vary greatly according to each individual.

After the age of 12, ability to learn a new language greatly decreases. In L2 acquisition, (Sakai 2005, p.818), cortical plasticity is possible until the age of 13 where the left IFG directs towards L1 specialization. At all ages, specific linguistic functions are subserved by a grammar center. Facts indicate that regional cerebral blood flow and cerebral metabolic rates increase until the age of 9 and after the age of 9, it starts to decrease. Twin studies have reported genetic factors, but studies on structures and functions regarding language acquisition and brain development are yet to have many areas to be completed in the future.⁴⁵

6. Comparison of Early L2 Learners to Late L2 Learners in Terms of Biological Constraints and Sub-effects Resulting from L2 Learning

As early L2 learning involves a large amount of the sensorimotor part of the neurological function of speech sound processing along with grammar processing, it is strongly affected by age of acquisition. A distinctive feature of early learners is that by forming 'native-language magnets' that shapes early phonological space, they are able to ignore small variations of phonological category.⁴⁶ Among early language learners, early ERP waves are seen; brain areas that are tightly tied to processing and producing sound based features. Also, there is a finding that when shown grammatical errors, there appears no difference in early learners' blood metabolism of the brain.⁴⁷

Although early exposure can influence neuro-functional organization in a special manner, especially in the sub-region in Broca's area, as opposed to neighboring locations within Broca's among late learners, changes in Wernicke's area are shown to be the same among both.⁴⁸ Initial stages of L2 learning can involve right hemisphere more than the left hemisphere, but with increased L2 fluency, left hemisphere involvement increases. Lateralization patterns among early bilinguals are similar whereas late bilinguals display disparate patterns. While late bilinguals may be left hemisphere dominant in L1, as a whole, language lateralization is quite similar among monolinguals and bilinguals.⁴⁹

There is a relatively higher level of increased activity in the prefrontal cortex among late bilinguals than early bilinguals, but no signs of blood metabolism increase is seen.⁵⁰ There is also some evidence that in late L2 learning, electrical activity is seen in larger brain networks.⁵¹ This involves functions such as reanalysis of grammatical errors relative to native speaker's networks. Technical support by cortical areas may decrease in areas with increased automation in processing. With increased demand for control in tasks, ACC and caudate may be required in bilingual production. However, it is clear that L2 does not lead to native like pattern of electrical activity.

Advantages for bilinguals include the effect of general executive control system on language control. Bilinguals outscore monolinguals in language tasks that use executive control.⁵² Another theory suggests that language and actions share the same cognitive resources, but this is not examined enough yet concerning bilinguals' executive control system.⁵³

Observations have further found evidence in the formational stages occurring as follows (Sakai, 2000). At the age of 3 to 6, anterior corpus callosum in frontal circuits, where vigilant mental state and organizing of action occurs, reaches peak growth rate in 60 to 80% locally. This period of age 3 to 6 also coincides with a period where isthmus growth rate stagnates or is late, thereby language functions and associative functions are not perfected yet. Contrarily, during ages 2 to 4, the frontal cortex sees doubling rates of glucose metabolism. From ages 6 to 13, fibre systems mediating language function and association grows at a rate faster than surrounding areas, and slows in growth at the age

of 11 to 15.⁵⁴ Temporal patterns at this period coincides with the end of the critical period. It could be said that ages between 6 and 13 is an appropriate period for effective language acquisition and learning because it is the period during which linguistic and associative functions develop. Further studies have indicated that among subjects aged 6 to 15, highest growth rate have been seen consisting of attainment in temporal-parietal systems which is specialized in linguistic function. Extreme growth was seen during age 6 to 15 at the callosal isthmus in all subjects, which is related to fine tuning in linguistic function at the end of child age.⁵⁵ Thompson (2000) states that 'cortico-cortical networks supporting rapid associative relay and language functions may myelinate more extensively and over longer periods than rostral fibre systems).

Thompson (2000) further observes,

'In a girl scanned twice exactly one year apart at ages 6 and 7 years, extreme growth (up to 85%) at the callosal isthmus contrasted with a comparatively quiescent region in the more rostral systems that innervate frontal and pre-frontal cortices. When a four year growth map was generated for a slightly older child, (11-15 years) growth rates were correspondingly reduced in every region. Nonetheless, growth patterns at the isthmus and splenium were still more rapid (20-25% locally) than in the more anterior rostrum and genu (near zero change). In an analysis of grey matter at the cortex, we recently observed a localized grey matter loss in frontal cortex that persists in normal subjects throughout adolescence even into adulthood. The gradual quiescence of growth at the rostral callosum around puberty may therefore be a precursor to a prolonged regressive process of grey matter loss through adolescence into adulthood in the frontal circuits it innervates (Thompson2000, p.191). However, cortical activation and their relation to linguistic functions can not be fully explained by non-invasive imaging techniques.⁵⁶

Selective integration of lexical-semantic information involves the putative region, which is equal to the left IFG extending from a triangular part to the orbital part, and is separable from simple lexical-semantic processing. While a sentence comprehension task is done in the left F3 and F30 and is selectively activated at discourse level, lexical decision tasks do not enhance left precentral sulcus. Overall, left-dominant activation in the frontal and temporo-parietal regions are apparent.⁵⁷

Sakai has demonstrated the existence of structural and functional connectivity in language acquisition and growth. Interacting populations of neurons are at work together during language processing. There has been an amodal commonality in functional dominance of the left cortical region. Also, syntactical and grammatical processing clearly takes place in a different part, namely left dorsal IFG and left lateral premotor cortex. Left dorsal IFG activation increases with PL improvement at early L2 acquisition, and drops as language acquisition progresses. During language development, a general law of activation change is seen. During early periods of language acquisition, cortical activation increases. During the middle period, maintenance of activation is apparent, and in the final period, activation seems to fall.⁵⁸

7. Conclusion

Bilingual children's L1 and L2 acquisition and neural development can be stated to involve multiple variables, such as age, developmental stages of neural organization, and individual L1 and L2 acquisition differences, including length and depth of exposure. Linguistic development happens in par with cerebral and cortical development until well into adolescence. Lexical information is processed in the declarative memory, whereas grammatical information uses procedural memory. Language learned later is separated into two memory systems. This article studied the nature of phonological intake, coding, and memory storage in multiple phases where each phase is inseparable from other procedures, because language processing system and the internal biological mechanism work closely together. The distinctive feature of early learners is that by forming native-language magnets, that shapes early phonological space, they are able to ignore small variations of phonological category. They also act as essential building units in language acquisition, especially for early L1 and L2 learners. Multiple areas in the brain have proven to have been involved where phonological processing occurs, thereby underscoring the specific nature of development in early L2 learners' brain organization.

Notes

- 1 Thompson, Paul, M. (2000)
- 2 Patricia K. Kuhl, (2010) Kuhl and Rivera-Gaxiola, (2008)
- 3 Grosjean, (2013). p.225
- 4 Sakai, K.L., (2005)
- 5 Jabr, F. (2013)
- 6 Gor, K. (2015)
- 7 deGroot, (2011)
- 8 de Groot, (2011)
- 9 de Groot, (2011) p.444
- 10 de Groot, (2011) p.435
- 11 de Groot, (2011) p.436
- 12 de Groot, (2011) p.439
- 13 de Groot, (2011) p.425
- 14 de Groot, (2011) p.425
- 15 de Groot, (2011) p.430
- 16 de Groot, (2011) p.432
- 17 de Groot, (2011) p.434
- 18 de Groot, (2011) p.434

- 19 de Groot, (2011) p.442
- 20 de Groot, (2011) p.442
- 21 de Groot, (2011)
- 22 de Groot, (2011)
- 23 de Groot, (2011) p.431
- 24 de Groot, (2011)
- 25 Sakai, (2005)
- 26 Kuhl, P., (2010)
- 27 E.H. レネバーク (1974) p.194-195
- 28 Lenneberg, (1967) Newport et. al (2001)
- 29 Sakai, (2005)
- 30 Sakai, (2005)
- 31 Kuhl, (2004) Zhang et. al (2005,2009)
- 32 Kuhl, (2004)
- 33 Kuhl, (2004)
- 34 Dijkstra, T. (2013).
- 35 ブルーム F.E. (2004)
- 36 森島 (2015)
- 37 Grosjean, (2013)
- 38 Skehan, (2009)
- 39 Vaid&Hall, (1991) de Groot, (2011) p.430
- 40 Hernandez (2013)
- 41 Genesee, (1989) Meisel, (2001)
- 42 de Groot, (2011) p.425
- 43 Kuhl, (2010) p.7
- 44 Kuhl, (2010)p.18
- 45 Sakai, (2005)
- 46 Hernandez, (2013) p.41
- 47 Hernandez, (2013)p.57
- 48 de Groot, (2011) p.431, Hull&Vaid (2006) p.459
- 49 de Groot, (2011) p.430~
- 50 Hernandez, (2013) p.51
- 51 Hernandez, (2013) p.50
- 52 de Groot, (2011) p.435
- 53 Coello, (2013)
- 54 Thompson, (2000)
- 55 Thompson, (2000)
- 56 Thompson, (2000)
- 57 Sakai, (2005)
- 58 Sakai, (2005)

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