ELLITE
Journal of English Language, Literature, and Teaching

Volume 08, No. 1, May 2023

Understanding Neuroscience, How The Brain Works, and The Implication on Grammar Teaching and Learning

***Indri Astutik[1], Peggy Magdalena Jonathans[2], Devinta Puspita Ratri[3], Yeni Mardiyana Devanti[4]**

[1,4] Universitas Muhammadiyah Jember, Indonesia; [2] Universitas Kristen Artha Wacana, Kupang; [3] Universitas Brawijaya Malang

(*indri@unmuhjember.ac.id)

First Received: 09-02-2023 *Final Proof Received: 24-05-2023*

Abstract

One of the human attributes is the ability to process language. Over the last few decades, we have learned a lot more about its neurological foundation that specific linguistic functions are believed to be supported by various brain's sections in left and right hemispheres. However, studies have shown that language comprehension and grammar depend on other areas of the brain outside the so-called Broca's region, which corresponds to Brodmann areas 44 and 45. It has been linked to an expanded brain activity including BA44, BA45, and BA47, the anterior insula (BA13), the mesial part of the supplementary motor area (the lateral expansion of BA6), and the bottom layer of the forebrain. Studies have also exposed the brain's memory systems in language learning, storage, and usage, which are called as declarative/procedural memory systems. Further, studies have unveiled that these declarative/procedural memory systems can be enhanced through interventions. Thus, understanding these issues is advantageous for language teachers/instructors to know how the brain works in learning a language and its grammar, which is vital to have effective teaching and learning. Such understanding may lead teachers to develop their syllabus and materials, select strategies and methods, and design various class activities that result in effective learning.

Keywords: Broca's area; Declarative/Procedural Memory; Grammar Processing; Language Processing; Neuroscience.

We all know that nearly all of language studies had, predictably, concentrated solely on language—how it is acquired or learned and what strategies may be used to teach or learn it. As a result, only a few SLA research implications affected certain teachers' instructional concepts, like the critical time hypothesis. New functions, on the other hand, frequently rely on pre-existing biological systems during evolution and development. Whether or not these neurological foundations have evolved further, this domain is presumably very dependent on them because language must finally be grounded in biology (Ullman & Lovelette, 2018). It designates that learning language in general and learning grammar, particularly, rely heavily on the brain's work.

The brain is the device where the mind and memory work. It indicates that the function of the brain is central in learning

DOI: http://doi.org/10.32528/ellite.v8i1.10063
Available Online at *jurnalunmuhjember.ac.id/index.php/ELLITE*
ISSN (Print) : 2527-4120
ISSN (Online) : 2528-0066

How to cite (in APA style):
Astutik, I., Jonathans, P.M., Ratri, D.P. & Devanti, Y.M., (2023). Understanding Neuroscience, How The Brain Works, and The Implication on Grammar Teaching and Learning. *English Language, Literature, and Teaching, 8*(1), 61-73 doi:10.32528/ellite.v8i1.10063

grammar which language teachers cannot neglect, therefore, teachers should associate their pedagogical activities in teaching grammar with neuroscience's work. However, this central aspect of learning seems to be neglected in teaching and learning grammar. In the grammar teaching and learning process, teachers merely emphasize the methods and strategies that appear have no relation with how the brain works. With the negligence of this central aspect of learning—how the brain works, the result of language teaching and learning may not be said satisfying.

The part of the brain responsible for language, known as the language-relevant cortex, consists of Broca's area located in the inferior frontal gyrus (IFG), Wernicke's area situated in the superior temporal gyrus (STG), along with certain regions of the middle temporal gyrus (MTG), and the inferior parietal and angular gyrus located in the parietal lobe (Friederici, 2011, p.1358). It is believed that learning grammar happened in the Broca's area (BA), i.e., BA44 and BA45 located in the left posterior inferior of the front part of the cortex. According to brain imaging data, the area is drawn in during the processing of complex grammatical constructions, whether they are a part of a natural or artificial grammar (Tettamanti et al., 2002; Musso et al., 2003; Friederici et al., 2006a, b). Additionally, an artificial structure's processing of objects that have been moved from their initial position adheres to the same pattern (Ben-Shachar et al., 2003; Santi and Grodzinsky, 2007). A recent study has shown, however, that the so-called Broca's area, which corresponds to BA44 and BA45, is not the sole area that influences language formation and grammar (Ardila, 2021). Language production has been linked to an expanded brain activity that includes BA44, 45, and 47 together with the substantia nigra, the posterior temporal lobe (BA13), and the mesiodistal portion of the ventral tegmental region (mesial extension of BA6), according to fMRI findings (Ardila et al., 2016; Bernal et al., 2015; Li et al., 2020; Tremblay & Dick, 2016).

Literature Review

Neuroscience and language processing

Since the initial finding discovered language functions are intimately related to brain tissue, scientists have indeed been fascinated by studying the neurological underpinnings of language. They have started to use various approaches to demonstrate how the brain functions and learning language. Research studies, then, employed various approaches such as new technologies like "electroencephalography (EEG), magnetoencephalography (MEG), and magnetic resonance imaging (MRI) with in vivo technique to monitor mental activity in the brain (fMRI) in addition to gray matter structure and white matter fiber tracts" (diffusion-weighted MRI)," have resulted in a significant growth in brain-based language studies (Friederici, 2011, p. 1357). However, it is still challenging to characterize the neural underpinnings of language and speech.

Before, it was believed that language processing was mainly concentrated in specific brain areas of the predominate frontal hemispheres. Therefore, comprehension functions were controlled by the Wernicke area, whilst production processes were handled by the Broca area. More widespread systems for language processing incorporating brain regions, cortex and subcortical have been proposed to replace this theory (Adamaszek & Kirkby, 2016). The Broca and Wernicke areas consequently connect to the symmetrical cortex, ipsilateral insula, and subcortical brain areas in both hemispheres, suggesting that the left inferior frontal and left superior temporal cortices are in charge of substantial language processing in both sentence production and perception (Friederici, et al., 2003; Shapiro & Caramazza, 2004).

Studies have reported that language production takes place in the Broca's area of IFG—inferior frontal gyrus, Wernicke's area of STG—superior temporal gyrus and sections

ISSN (Print) : 2527-4120
ISSN (Online) : 2528-0066

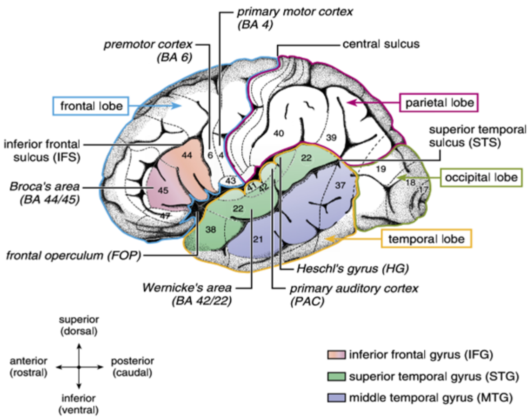

Figure 1 Anatomical and cytoarchitectonic details of the left hemisphere (Friederici, 2011, p. 1359).

of MTG—middle temporal gyrus and the inferior parietal and angular gyrus in the parietal lobe. Microanatomical subregions can be specified inside this macro anatomically defined regions, as it shown in Figure 1 (Frederici, 2011). It appears to be important because the larger Broca's region has repeatedly been cited as helping various aspects of language production. This Broca's area is cytoarchitectonically divided into Brodman area (BA) 44, the par opercularis and BA 45, and the pars triangularis (Amunts et al., 1999). Area 45 can be separated into two parts based on receptor architecture: a more anterior area 45a bordering BA 47 and a more posterior area 45p bordering BA 44 (Amunts et al., 2010). Additionally, area 44 can be divided dorsally (44d) and ventrally (44v) using receptorarchitectonics. When taking into account the extremely fine neurobiological range of effects of this area, different language studies have assigned distinct roles to area 45 as well as area 44, which are now linked to several subdomains inside 45 (45a versus 45p) and 44 (44d versus 44v) (Frederici, 2011).

In language processing, there were two stream models—the ventral pathway and the dorsal pathway. The ventral route has been said to enable mapping from sound to meaning, on the other hand, the dorsal route, which ties the dorsal-most portion of the temporal lobe posterior to the frontal lobe posterior, supports auditory-motor integration (Hickok & Poeppel, 2007). Further, there is proof that there are two adjacent neural routes, supplementary motor hemisphere receives one from the superior temporal gyrus (dorsal pathway I) and one from the supplementary motor hemisphere to BA 44 (dorsal pathway II), with the former enabling sound-to-motor mapping, and the latter supporting more advanced language features (Frederici, 2011). While orienting the system towards the target language during early language acquisition, this dorsal pathway I subserving auditory-motor integration is already of key importance (Hickok & Poeppel, 2007). The development of a dorsal fiber tract (dorsal route II) that connects the temporal lobe to Broca's region in the IFG appears to be functionally important to higher-level semantic and syntactic language functions (Brauer et al., 2011).

Neuroscience and grammar processing

The study of the rules governing how words change their shape and combine with other words to produce sentences is commonly used to describe grammar as a system of rules that governs how words (morphology) and sentences (syntax) are formed in a particular language (Cambridge Dictionary, Huddleston & Pullum, 2002; Oxford Dictionary). Grammar, from a concise standpoint, relates to the structure of certain language or the connection between morphemes and words (morphology and syntax) (Ardila, 2021). Grammar is usually thought to be the most advanced and complex step of linguistic development (Bickerton, 2007). A universal or "core syntax" or grammar has also been suggested as having significant structural similarities throughout all human languages (Chomsky, 1980).

Grammar-processing regions are found in cortical and subcortical circuits of the brain. Developments in imaging technologies and neuroscience are expanding our understanding of how and where the brain processes the various complexities of grammar in human language, as evidenced by burgeoning literature on the subject (Adamaszek & Kirkby, 2016).

The hippocampus and basal ganglia are thought to play a role in the cerebral networks that deal with different grammatical elements (Booth, et al., 2007; Friederici, 2004; Kotz, Schwartze, & Schmidt-Kassow, 2009). Recent studies have shown that language processing and grammar are not solely dependent on Broca's region, which corresponds to Brodmann areas 44 and 45 in the brain (Ardila, 2021).

In multiple investigations, it was discovered that the lateral anterior temporal lobe activated more forcefully when sentences containing syntax were compared to lists of words without syntax (Humphries et al., 2006). The formation of phrase structure specifically has been thought to be promoted by this rise in anterior STG/STS activity, as it is evident even when contrasting meaningless "pseudoword" categories with meaningless pseudoword sentences (i.e., phrases in which function words remain in their proper structural position but pseudowords substitute content words) (Friederici et al., 2000, p. 294; Humphries et al., 2006). According to a study, syntactic breaches caused more activation in the anterior STG than semantic violations (Friederici et al., 2003). Additionally, studies contrasting genuine word (sentences and list of words) with pseudoword (sentences and list of words) paradigms discovered no major semantic effect in the anterior STG/STS (Friederici et al., 2000; Humphries et al., 2006). In conclusion, it appears that the front temporal cortex is involved in understanding semantic and grammatical information. Its principal objective during phrase analysis may naturally be multidimensional.

During language comprehension, the posterior temporal lobe has also been discovered to be engaged. Sentence-level specific semantic information has also been shown to modify activation in the posterior STG/STS, primarily when the input information deals with the processing of the relationship between the verb and its arguments, whether it be in correct phrases when assessing a sentence's meaning near probability with regard to the verb argument link or in incorrect sentences when taking into account a sentence's meaning near probability related to the verb argument connection (Obleser & Kotz, 2010), or in statements when the verb and its arguments have a constraint violation (Friederici, et al., 2003).

The inferior frontal gyrus (IFG), especially Broca's area, contributes to language production and comprehension processes. It is also considered to responsible for verbal working memory (WM). Some parts of Broca's area are believed to have different functions, such as BA 44 supports constructing a syntactic framework, BA 44/45 contributes in assigning a theme to a role as well as supports the computation of syntactic movement, BA 45/47 maintains semantic processes, and BA 44/45/47 integrate different aspects in language. BA 44 is the essential part of the brain for decoding syntactic complexity (Friederici, 2011).

Broca's region is clearly implicated in WM in particular, and it is believed that the processing of syntactically complicated sentences necessitates the use of some WM resources. Due to the fact that WM interacted with moving phrase processing in BA 45 but not with other sentence types processing, researchers believe Broca's area's role in WM is exclusive to movement processing. The distance between the subject noun and its associated verb was used to operationalize WM and syntax as the number of recursive word vectors (Friederici, 2011). A study indicated that the IFS contained the primary effect of distance reflecting WM, whereas BA 44 had the primary effect of hierarchy reflecting syntactic complexity (Makuuchi et al., 2009). The findings supported a previous study indicating that the amount of noun phrase combinations in jumbled sentence constructions enhanced BA 44's activity in a parametric way with increasing syntactic complexity (Friederici et al., 2006b).

Neuroscience in teaching and learning

There is much variation in the rate, efficiency, and ultimate success of second

ISSN (Print) : 2527-4120
ISSN (Online) : 2528-0066

language (L2) learning. It is crucial to figure out what factors cause such wide variation among students. Studies have proved that high-level cognitive functions like language, from a neurophysiological standpoint, require synchronized activity inside and throughout particular brain regions. Mastering the neurological foundation of human communication requires research into connections between various networks and regions of the brain. Studying brain rhythms, their topographical features, task- and state-dependent development, and dynamics is one technique to investigate such interactions. These neural oscillations are at the core of the brain's coordinated activity and are thought to be one of the most important mechanisms for learning and neural plasticity (Benchenane et al., 2010; Uhlhaas & Singer, 2010).

Learning is a process of modifying the brain that involves the formation of new neural connections and memory regions. It is said to be successful when changes in brain activity are required for proper information storage and retrieval. Furthermore, insights from neuroscience study into learning processes are critical for designing instructions that consider how the brain learns and prepares the brain for learning. Educators should examine how neuroscientists' studies on working memory and long-term memory might be applied to their students' learning (Kweldju, 2019b). In short, it is educational neuroscience that focuses on how to apply neuroscience to education. Thus, instructions should examine the optimum strategy to activate those brain regions engaged in various component skills, including grammar.

Neuroplasticity, on the other hand, is the ability of the brain to alter and adapt as a result of experience. It develops and forms new synaptic connections during life. Plasticity occurs throughout life and includes cells other than neurons in the brain, such as glial and vascular cells. Learning, experience, and memory creation can all lead to it. According to this theory, all people can learn conscious and unconscious cognitive, social, and physical abilities throughout their lives, which is the primary brain underpinning for lifelong learning (Kweldju, 2019b). The capacity to learn conscious and unconscious cognitive relates to the two systems of memory in the brain—declarative and procedural memory systems.

Declarative and procedural memory systems for learning grammar

The declarative/procedural (DP) paradigm proposes that language learning, storage, and usage are all dependent on two kinds of brain memory systems—declarative and procedural memories. The model of DP memory offers conceptual context for determining which approaches should be applied to learning a language and under what conditions. It advocates that learning language generates two aspects in the brain learning and memory systems. To increase language learning, particularly second language acquisition (SLA), the DP models provide strong hypothesized justifications for doing so, as well as precise recommendations for when and how to do so (Ullman & Lovelett, 2018).

The declarative memory system is the brain's system responsible for explicit knowledge, which can be brought to conscious awareness. The hippocampus and other components of the medial temporal lobe provide the foundation of this system. Any explicit knowledge was presumably obtained through this memory system because declarative memory appears to be the only long-term memory system that supports it. Even with a single exposure of stimuli, information in declarative memory can be learned quickly, while subsequent exposures—repetition, enhance memories. Declarative memory learning capacities in second language acquisition grow during childhood, reach their peak in adolescence and early adulthood, and then decline. As a result, an older child or young adult is more likely to succeed in this system than a young child (Ullman & Lovelett, 2018).

The brain's procedural memory system is in charge of processing implicit learning for cognitive and perceptual motor abilities like mapping, sequencing, constraints, and categorizations. The prefrontal (pre) sensorimotor regions may be more important for thinking processes after they have been automated, whereas the ganglion cells are essential for learning and remembering new skills. Although learning in this system takes longer than learning in declarative memory because it happens gradually, what is eventually learnt seems to be processed more rapidly and naturally than information stored in declarative memory. Early in infancy, learning and consolidation of procedural memory appear to be active, unlike declarative memory; however, it may become somewhat reduced over childhood and adolescence (Ullman, 2005; Ullman & Lovelett, 2018).

Declarative memory learns quickly, therefore, rule-governed grammar's constituent parts should be absorbed first in the system. Due to its adaptability, declarative memory should learn both non-idiosyncratic (grammatical) and idiosyncratic (linguistic) constituent parts of language. Nonetheless, because procedural memory is well suited for learning implicit knowledge about rules, sequences, and categories, it should gradually absorb grammatical knowledge as well.

Grammar is believed to be learned and stored in declarative and procedural memory in different ways; for example, fragments or explicit rules in the first case, and fast and automatic application of implicit rules in the second. As an illustration, a learner might initially memorize pieces of complicated shapes like walked or the cat while concurrently learning the fundamental compositional rules in procedural memory. After acquiring sufficient language proficiency, procedural memory-based grammatical processing ought to have a tendency to take precedence over comparable declarative information, leading to an increase in grammatical automated processes. This knowledge leads to the assumption that L2 learners with stronger procedural memory establish and process their grammar to a greater extent, leading to improved grammatical abilities, because procedural memory appears to be weakened rather than extinct in older learners, including adults. However, a greater dependence on procedural memory may result from the absence of explicitly teaching in immersion contexts and implicit SLA learning models (Ullman & Lovelett, 2018).

Developing learning and memory

Research on memory has found a number of strategies, such as approaches that can help one or both systems work better. Based on the current DP model, such treatments should improve language learning, storage, and usage. Some of these treatments are rather intrusive and directly address the underlying brain systems such as medications. However, the attempts will concentrate on non-invasive methods that are more easily adaptable to second language learning and education (Ullman & Lovelett, 2018).

There are two broad types of non-invasive interferences—item level approaches and learner level approaches. Item level approaches are interventions/attempts to enhance learning and memory through specific items or skills applying to particular learners, whereas learner level approaches are interventions/attempts/approaches that focus on individual learners. In the item level approaches, five categories may be proposed—spaced repetition (the spacing effect), retrieval practice (the testing effect), deep encoding (levels of processing), gesture-based learning, and mnemonic strategies (Ullman & Lovelett, 2018).

Spaced repetition involves examining information at progressively greater intervals over time. By separating the study sessions, it strengthens the memory and enhance long-term retention. It is also known as distributed

 ISSN (Print) : 2527-4120
ISSN (Online) : 2528-0066

practice or the spacing effect; that is, providing sequential spaces between recurrent exposures to the same item (Cepeda et al., 2006). The distributed practice effect refers to how the time intervals between study sessions, known as "interstudy intervals (ISI)", affect learning outcomes on subsequent tests. In spacing studies, there are typically two study sessions separated by an ISI, with a fixed retention interval between the final study session and a later test. Performance is compared across different durations of ISI. Even in studies with more than two study sessions, the retention interval still represents the time gap between the last study session and the final test (Cepeda et al., 2006, p. 354). Some activities reflecting space repetitions are: 1) Flashcards i.e., preparing a collection of cards with questions or essential concepts on one side and their corresponding answers or explanations on the other side. Consistently review the flashcards, placing emphasis on more frequent review for the cards that pose greater difficulty; 2) Incremental reading, i.e., breaking down larger texts/topics into the smaller ones. Reading and understanding one section at a time, followed by scheduled intervals of review. This method strengthens the grasp of the material and enhances long-term retention; 3) Study schedules i.e., creating study schedules that incorporate regular review sessions for previously learned material. For example, allocate specific time slots each week to revisit and review concepts from previous chapters or units. This approach helps reinforce the material and aids in long-term retention; 4) Practice quizzes by consistently evaluate the knowledge through practice assessments and self-evaluations. Distribute these tests over time to reinforce the material and identify areas that require further review. These activities strengthen the memory and enhance long-term retention (Bjork, 1994; Cepeda et al., 2006; Karpicke & Roediger, 2008; Roediger, & Butler, 2011).

Retrieval practice, also known as the testing effect, involves recalling learned information from memory rather than simply reviewing or restudying it (Roediger and Butler, 2011). Retrieval practice is frequently successful even in the absence of feedback, but the presence of feedback amplifies the advantages of testing. Moreover, retrieval practice facilitates the acquisition of knowledge that can be flexibly recalled and applied in various contexts. Some examples of retrieval practice activities are: 1) Flashcards to quiz on the key facts/points, concepts, or vocabulary; practice test to engage in test-taking activities or create informal tests that closely resemble the conditions of the actual evaluation; 2) Free recall, an exercise to memorize or recall as much information as possible about a specific topic or subject without using any study materials by writing down or reciting aloud everything can be remembered; 3) Concept mapping by creating concept maps or diagrams that illustrate the relationships between different ideas or concepts to actively recall and organize information from memory to construct the map; 4) Fill in the blanks by taking study materials or textbook passages and remove key words or phrases, and then, fill in the blanks with the missing information from memory (Agarwal et al., 2012; Karpicke & Roediger, 2008; Roediger, & Butler, 2011).

Deep encoding refers to an active and meaningful cognitive process that enhances understanding, comprehension, and long-term memory retention. According to Craik and Lockhart (1972, p. 675) the concept of sequential or hierarchical processing stages is commonly known as "depth of processing," where greater "depth" indicates a higher level of semantic or cognitive analysis. During deep encoding, individuals concentrate on the significance and relevance of the information, establishing connections with their existing knowledge and personal experiences. The activities that promote deep encoding include: 1) Elaboration that involves establishing connections between newly acquired information and existing knowledge or personal experiences. By making associations and drawing upon prior understanding, one can deepen comprehension and improve retention. This can be achieved through various means such as creating analogies, visualizing information through diagrams, or explaining concepts using one's own words; 2) Semantic processing is another form of deep encoding. It involves directing attention to the meaning of information rather than its superficial characteristics. It entails reflecting on the significance and implications of the material and striving to comprehend the underlying concepts and their interconnections; 3) visualization includes visualizing the knowledge being taught. Imagining the topic's details, spatial linkages, and interactions improves recall and comprehension; 4) Self-explanation involves verbally articulating the material to oneself, as if teaching someone else. By expressing the steps, reasons, and connections involved, individuals actively engage with the content, leading to a deeper understanding of the material; 5) Relational learning involves actively seeking connections between newly acquired information and pre-existing knowledge. It entails identifying similarities, differences, and relationships between concepts. This approach promotes a more comprehensive and integrated understanding of the subject matter. These deep encoding activities are cognitive processes characterized by active and meaningful engagement that boosts understanding, comprehension, and the long-term retention of information (Bjork, 1999; Craik, & Lockhart, 1972; Roediger, & Karpicke, 2006).

Gesture-based learning, also referred to as the enactment effect, involves using contextually appropriate gestures alongside word learning (Ullman & Lovelett, 2018). This approach enhances the learning process by incorporating physical movements that align with the meaning and context of the words being taught (Macedonia, 2014). Some examples of the activities of gesture-based learning are: 1) Role-play involves participating in interactive activities where gestures are utilized to communicate and convey meaning. This can encompass enacting scenarios or dialogues that necessitate physical gestures to augment comprehension; 2) Gesture mimicry entails observing and imitating gestures demonstrated by others. This activity facilitates the learning and comprehension of new concepts or instructions through the process of imitation; 3) Incorporate gesture-based instructions by utilizing hand movements or body gestures to communicate directions or instructions during learning activities. This approach involves using gestures to guide others in performing specific tasks or actions; 4) Enhance vocabulary learning through gestures by incorporating physical movements when acquiring new words or phrases in a foreign language. Match specific gestures to corresponding words or phrases to aid memory and facilitate recall; and 5) Gesture-based storytelling enriches the narrative experience and promotes comprehension. The activities of gesture-based storytelling utilize hand movements, facial expressions, and body gestures to effectively convey emotions, actions, and events within the story. The applications of gesture-based learning activities have benefits and enhance understanding and communication (Alibali & Nathan, 2012; Goldin-Meadow, 2003; Özyürek, 2014).

Mnemonic strategies, such as the method of loci or memory palace technique, involve mentally associating the information to be learned with imageable locations. By mentally mapping the material onto specific places, this technique enhances memory retention and recall (Lea, 1975; Ullman & Lovelett, 2018). Some examples of mnemonic strategies include: 1) Acronyms involve creating memorable words or phrases by using the initial letters of words in a list or sequence. This mnemonic strategy aids in remembering information in a specific order by associating it with a concise and memorable acronym; 2) Visualization entails creating vibrant and imaginative mental images that are associated with the information aiming to remember. By

 ISSN (Print) : 2527-4120
ISSN (Online) : 2528-0066

generating vivid mental pictures, it enhances memory recall by establishing strong visual connections to the content; 3) The method of loci utilizes spatial memory by mentally associating specific items or concepts with various rooms or locations in a familiar place, such as a house. This technique establishes a visual and spatial framework, facilitating recall and organization of information; 4) Chunking involves dividing larger pieces of information into smaller, manageable chunks. By grouping related information together, this mnemonic strategy enhances memory retention and makes it easier to remember and recall the content; 5) Rhymes and songs: Develop rhymes, chants, or songs that incorporate the desired information for better memorization. The rhythmic patterns and melodies of these rhymes or songs contribute to improved memory retention (Dunlosky et al., 2013; Roediger, & Butler, 2011; Smith & Vela, 2001).

All the five approaches seem to support declarative memory, while spacing may also help the procedural memory. The learner level approaches seem less popular, but they include sleep which is believed to improve declarative and/or procedural memory, aerobic exercise, which is related to adding the volume of the hippocampus and aspects of declarative memory, diet, which is believed to improve declarative memory, and mindfulness which seems beneficial for declarative memory but inhibits procedural memory (Ullman & Lovelett, 2018).

Discussion

Based on neuroscience research findings, it is clear that teachers are suggested to know about neuroscience for the basis of their teaching and learning practices. As Kweldju (2019b) states, teachers must have a basic understanding of neuroscience to affect their students' behavior, and parents must be aware of it as well. If teachers want to make the classroom a better place for their students, they must first understand what is going on inside their students' heads (Kelly, 2017). Although there is little known from neurological evidence, Kweldju (2019b) affirmes, certain discoveries from brain studies tell teachers what they already know from training, experience, and intuitions. Bloom's taxonomy of cognitive domains, which includes remembering, comprehending, applying, analyzing, evaluating, and creating and was devised without any consideration of neurobiology, has since been revealed to be remarkably parallel with neuroscience results. The neocortex's frontal lobes are essential for higher-order thinking capabilities, and they become more active when confronted with conflicting situations. Every different functional unit of the brain is also directly related to the frontal lobe. It helps with attention management, working memory storage, and temporal integration. Currently, cognitive neuroscience can illustrate how the brain architecture of more creative and less creative people differ. Creative people, Jung et al. (2010) asserts, have thicker cortical layers in the right posterior cingulate and right angular gyrus and more frontal activity on both sides. Non-creative people's cortical thickness, on the other hand, is located in the lingual gyrus and left the lateral orbitofrontal area.

Since neuroscience research findings also uncovered the temporal lobe and inferior temporal gyrus' role in learning language grammar, teachers need to understand these issues. They need to know, for example, that the lateral anterior temporal lobe functions more extensively when learning sentences compare to learning word lists. It is clear when contrasting meaningless list of pseudowords with meaningless pseudoword sentences (sentences in which function words remain in their correct syntactic locations but pseudowords replace content words) that this increase in activation in the anterior STG/STS has been interpreted to enhance the development of phrase structure in particular (Friederici et al., 2000; Humphries et al., 2006). The inferior frontal gyrus (IFG), especially Broca's area, is believed to contribute to language production and comprehension processes—syntactic structure building, thematic role assignment, computation of syntactic movement, semantic processes, and many different aspects of language. Broca's region is clearly implicated in WM in particular, and it is believed that the processing of syntactically complicated sentences necessitates the use of some WM resources (Friederici, 2011).

It is also crucial for teachers to understand how the brain's memory works in learning grammar since language learning, storage, and usage are all dependent on these two brain memory systems. Understanding this point of issue will help teachers develop the syllabus and materials, selecting the strategies and methods, designing the activities for the teaching-learning process of their grammar classes. They have to understand that memory system take two forms—declarative and procedural memory systems. Declarative memory, which takes place in the hippocampus hemisphere, is responsible for the explicit knowledge relating to conscious awareness. In contrast, procedural memory, which occurs in the basal ganglia, handles implicit learning and processing of perceptual-motor and cognitive skills such as navigation, sequencing, rules, and categories (Ullman & Lovelett, 2018). Thus, by understanding the procedure of the memory systems, teachers may have the awareness to sequences their teaching practices based on the theories of how the brain works. By respecting these theories, teaching and learning grammar can be more meaningful and can get optimal results.

Understanding the development or enhancement of declarative/procedural memory (DP) systems cannot be neglected by the teachers responsible for enhancing students' understanding of grammar materials in language classes. Having a good understanding of the interventions that can be made to enhance students' cognitive capacity is a crucial aspect of teaching. Teachers should know that the enhancement can be done in two categories—item-level and individual-level approaches. Item level approaches comprise five aspects of enhancement, i.e., spaced repetition (the spacing effect), retrieval practice (the testing effect), deep encoding (levels of processing), gesture-based learning, and mnemonic strategies (Ullman & Lovelett, 2018). Based on the theories, to promote students' good understanding of the material and to lead effective teaching and learning, it is not true that teaching and learning grammar must heavily fall on the fun ways only, but it must be challenging as well.

Conclusion

Neuroscience research findings have contributed significantly to the process of learning language by opening a new perspective of how the brain works for language processing which directly influences the older paradigm of teaching and learning a language which was formerly based on SLA and language research findings solely without paying attention to the role of the brain in language processing. This new perspective is crucial for language teaching and learning by giving an insightful understanding of the brain and its hemispheres, which work with language processing, leading teachers to be aware of the role of the brain in learning.

The findings of the grammar processing in some hemispheres of the brain give fruitful insight for teachers and contribute to the advancement of the brain, especially the memory system responsible for language learning, storage, and usage. It suggests that the language processing in the brain may lead teachers to design syllabus and material, select strategies and methods, and design various activities that may respect fun activities and challenging ones. Thus, future research may concentrate on practices that enhance declarative and procedural memory systems by bringing interventions either in the item level approaches or individual level approaches and intervention practices to enhance effective grammar learning.

ISSN (Print) : 2527-4120
ISSN (Online) : 2528-0066

References

Adamaszek, M. & Kirkby, K. C. (2016). Cerebellum and Grammar Processing. In P. Mariën & M. Manto (Eds.), *The Linguistic Cerebellum* (pp. 81-105). Academic Press, Elsevier Inc.

Agarwal, P. K., Bain, P. M., & Chamberlain, R. W. (2012). The value of applied research: Retrieval practice improves classroom learning and recommendations from a teacher, a principal, and a scientist. *Educational Psychology Review*, 24(3), 437-448.

Alibali, M. W., & Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from learners' and teachers' gestures. J*ournal of the Learning Sciences*, 21(2), 247-286.

Amunts, K, Lenzen M, Friederici AD, Schleicher A, Morosan P, Palomero-Gallagher N., & Zilles, K. (2010). Broca's region: Novel organizational principles and multiple receptor mapping. *PLoS Biol* 8, e1000489.

Amunts, K., Schleicher, A., Bürgel U., Mohlberg, H., Uylings, H. B., & Zilles, K. (1999). Broca's region revisited: cytoarchitecture and intersubject variability. *J Comp Neurol*, 412, 319 –341.

Ardila, A. (2021). Grammar in the brain: Two grammar subsystems and two agrammatic types of aphasia. *Journal of Neurolinguistics*, 58, 100960.

Ardila, A., Bernal, B., & Rosselli, M. (2016). Why Broca's area damage does not result in classical Broca's aphasia. *Frontiers in Human Neuroscience*, 10, 249

Benchenane, K., Peyrache, A., Khamassi, M., Tierney, P. L., Gioanni, Y., Battaglia, F. P., & Wiener, S. I. (2010). Coherent theta oscillations and reorganization of spike timing in the hippocampal- prefrontal network upon learning. *Neuron*, 66(6), 921–936.

Ben-Shachar, M., Hendler, T., Kahn, I., Ben-Bashat, D., & Grodzinsky, Y. (2003). The neural reality of syntactic transformations: evidence from functional magnetic resonance imaging. *Psychol*. Sci. 14, 433–440.

Bernal, B., Ardila, A., & Rosselli, M. (2015). Broca's area network in language function: A pooling-data connectivity study. *Frontiers in Psychology*, 6, 687.

Bickerton, D. (2007). Language evolution: A brief guide for linguists. *Lingua*, 117, 510–526. https://doi.org/10.1016/j.lingua.2005.02.006

Bjork, R. A. (1994). Memory and metamemory considerations in the training of human beings. In J. Metcalfe & A. Shimamura (Eds.). *Metacognition: Knowing about knowing* (pp. 185-205). MIT Press.

Bjork, R. A. (1999). Assessing our own competence: Heuristics and illusions. In D. Gopher & A. Koriat (Eds.). *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 435-459). MIT Press.

Booth, J. R., Wood, L., Lu, D., Houk, J. C., & Bitan, T. (2007). The role of the basal ganglia and the cerebellum in language processing. *Brain Research*, 1133(1), 136–144.

Brauer J., Anwander A., & Friederici A. D. (2011). Neuroanatomical prerequisites for language functions in the maturing brain. *Cerebral Cortex*, 21, 459 – 466.

Cambridge Dictionary. Retrieved from https://dictionary.cambridge.org/dictionary/english/grammar.

Cepeda, N. J., Pashler, H., Vul, E., Wixted, J. T., & Rohrer, D. (2006). Distributed practice in verbal recall tasks: A review and quantitative synthesis. *Psychological Bulletin*, 132(3), 354-380.

Chomsky, N. (1980). *Rules and representations.* Oxford, Blackwell.

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, 11(6), 671-684.

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest*, 14(1), 4-58.

Friederici, A. D. (2004). Neural basis of syntactic processes. In M. S. Gazzaniga (Ed.). *The cognitive neurosciences* (pp. 789–801). Massachusetts Institute of Technology Press 3rd.

Friederici, A. D. (2011). The brain basis of language processing: From structure to function. *Physiological Reviews* 91(4), pp. 1357-1392.

Friederici, A. D., Bahlmann, J., Heim, S., Schubotz, R.I., & Anwander, A. (2006a). The brain differentiates human and non-human grammars: Functional localization and structural connectivity. *Proc. Natl. Acad. Sci. USA*. 103, 2458–2463.

Friederici, A. D., Fiebach, C. J., Schlesewsky, M., Bornkessel, I., & von Cramon, D. Y. (2006b). Processing linguistic complexity and grammaticality in the left frontal cortex. *Cerebral Cortex* 16, 1709–1717.

Friederici, A. D., Meyer M., & von Cramon D. Y. (2000). Auditory language comprehension: an event-related fMRI study on the processing of syntactic and lexical information. *Brain Lang* 74, 289 –300.

Friederici, A. D., Rüschemeyer, S. A., Hahne, A., & Fiebach, C. J. (2003). The role of the left inferior frontal and superior temporal cortex in sentence comprehension: localizing syntactic and semantic processes. *Cerebral Cortex*, 13, 170–177.

Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think*. Belknap Press.

Hickok, G. & Poeppel D. (2007) The cortical organization of speech perception. *Nature Reviews Neuroscience* 8, 393– 402.

Huddleston, R. P., & Pullum, G. (2002). *The Cambridge grammar of the English language*. Cambridge, UK: CUP.

Humphries, C., Binder J. R., Medler D. A., & Liebenthal E. (2006). Syntactic and semantic modulation of neural activity during auditory sentence comprehension. *J Cogn Neurosci* 18, 665–679.

Jung, R. E., Segall, J. M., Jeremy Bockholt, H., Flores, R. A., Smith, S. M., Chavez, R. S., & Haier, R. J. (2010). Neuroanatomy of creativity. *Human Brain Mapping*, 31(3), 398-409.

Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science*, 319(5865), 966-968.

Kelly, C. 2017. The BrainStudies Boom: Using Neuroscience in ESL/EFL Teacher Training. In T.S. Gregerson & P. Machtyre (Eds.), I*nnovative practices in language teacher education: Spanning the spectrum from intra- to inter-personal professional development* (pp.79102). Springer.

Kotz, S. A., Schwartze, M., & Schmidt-Kassow, M. (2009). Non-motor basal ganglia functions: a review and proposal for a model of sensory predictability in auditory language perception. *Cortex*, 45(8), 982–990.

Kweldju, S. (2019b). Educational neuroscience for second language classrooms. *J-ELLiT* 3(2), pp. 1-9.

Lea, G. (1975). Chronometric analysis of the

ISSN (Print) : 2527-4120
ISSN (Online) : 2528-0066

method of loci. Journal of Experimental Psychology: *Human Perception and Performance* 104, 95–104.

Li, Q., Ferraro, G. D., Pasquini, L., Peck, K. K., Makse, H. A., & Holodny, A. I. (2020). Core language brain network for fMRI language task used in clinical applications. *Network Neuroscience,* 4(1), 134–154.

Macedonia, M. (2014) Bringing back the body into the mind: Gestures enhance word learning in foreign language. *Frontiers in Psychology* 5, 237–84.

Makuuchi, M., Bahlmann, J., Anwander, A., & Friederici, A. D. (2009). Segregating the core computational faculty of human language from working memory. *Proc Natl Acad Sci USA*, 106, 8362– 8367.

Musso, M., Moro, A., Glauche, V., Rijntjes, M., Reichenbach, J., Buchel, C., & Weiller, C. (2003). Broca's area and the language instinct. *Nat. Neurosci*. 6, 774–781.

Obleser, J. & Kotz, S. A. (2010). Expectancy constraints in degraded speech modulate the language comprehension network. *Cerebral Cortex* 20, 633– 640.

Oxford Dictionary. Retrieved from https://en.oxforddictionaries.com/definition/grammar.

Özyürek, A. (2014). Hearing and seeing meaning in speech and gesture: Insights from brain and behavior. P*hilosophical Transactions of the Royal Society B: Biological Sciences*, 369(1651), 20130296.

Roediger, H. L., & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. *Trends in Cognitive Sciences*, 15(1), 20-27.

Roediger, H. L., & Karpicke, J. D. (2006). The power of testing memory: Basic research and implications for educational practice. *Perspectives on Psychological Science*, 1(3), 181-210.

Santi, A. & Grodzinsky, Y. (2007). Working memory and syntax interact in Broca's area. *Neuroimage* 37, 8–17.

Shapiro, K., & Caramazza, A. (2004). The organization of lexical knowledge in the brain: the grammatical dimension. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 803–814). Massachusetts Institute of Technology Press 3rd.

Smith, S. M., & Vela, E. (2001). Environmental context-dependent memory: A review and meta-analysis. *Psychonomic Bulletin & Review,* 8(2), 203–220. https://doi.org/10.3758/BF03196157

Tettamanti, M., Alkadhi, H., Moro, A., Perani, D., Kollias, S., & Weniger, D. (2002). Neural correlates for the acquisition of natural language syntax. *Neuroimage* 17, 700–709.

Tremblay, P. & Dick, A. S. (2016). Broca and Wernicke are dead, or moving past the classic model of language neurobiology. *Brain and Language*, 162, 60–71.

Uhlhaas, P. J., & Singer, W. (2010). Abnormal neural oscillations and synchrony in schizophrenia. *Nature Reviews Neuroscience*, 11(2), 100–113.

Ullman, M. T. (2015). The declarative/procedural model: A neurobiologically motivated theory of first and second language. In VanPatten B and Williams J (eds.) T*heories in second language acquisition: An introduction 2nd edition*. Routledge, pp. 135–58.

Ullman, M. T. & Lovelett, J. T. (2018). Implications of the declarative/procedural model for improving second language learning: The role of memory enhancement techniques. *Second Language Research* 34(1), pp. 39 –65.