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Syntax in the Brain:
In Consideration for the Discussion of Cerebral Inner World

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On the one hand, linguists in the field such as generative and cognitive grammar have scarcely discussed how the linguistic knowledge actually exists in the brain. In generative grammar, for example, language acquisition device is thought to be in the black box. However, on the other hand, brain sciences have gradually revealed the structure of the brain and have made many discoveries in the field. One of them is the mirror system in the brain. This paper will show that how the syntactic knowledge can intrinsically exist in the brain is able to be discussed when the discoveries in the brain sciences are considered from the perspective of the discussions which have been held in Sato's several papers since Sato (1995). Each word can contain the syntax of its own. Predicate words can especially carry the information of the sentence structures. A sentence pattern used for a verb is set by the meaning of the verb and the verb decides the meaning of the sentence in which the verb is used.

Key Words: syntax, the brain, the mirror system, the cerebral inner world, grammar, language

Introduction

In the theory of generative grammar, it is postulated that the language acquisition device is in the brain and the knowledge of grammar is innate. According to the explanation in cognitive grammar, languages are acquired through the diverse general cognitive abilities. However, where and how the syntax exists in the brain has scarcely been discussed so far (cf. Cognitive linguistics, 2013; Theory of grammar, 2013). Meanwhile, a number of new things such as the mirror neuron system have been discovered in the brain sciences (Keysers, 2016; cf. Mushiake, 2019).

Defining meaning as *connections between Images (IMAGEs) in the brain*, Sato (1995) presents a language model, which can be thought to be in the brain actually. On the basis of the model, Sato (2013) postulates the existence of Cerebral Inner World (CIW) and discusses the probability of psychological reality of syntax in the brain. In addition, Sato (2019) shows that several grammatical items are affected by something psychological and talks over the psychological reality of grammar.

In this paper, in consideration for the discussion of CIW, where and how syntax can actually exist in the brain will be considered concretely.

Language in the brain

What is the function of language in the brain? Language function (2013) refers to *communicative function* and *behavior-regulation-function* as language functions. However, it does not explain how and why language carries out such functions? It appears that other animals such as chimpanzees also communicate something and regulate some behavior by using various means (cf. Matsuzawa, 2019). Is language really needed in order for human beings to communicate and regulate behavior? Does the brain have to promote the development of language only for such functions?

Index and manipulation functions of language should lead to communicative function and behavior-regulation-function. It seems natural that language has necessarily developed coupled with the other cerebral functions. Sato (1995) says that what are experienced through sense organs are named, or are given indexes through language, and the images named through language can be manipulated by using language. Sato regards the naming and manipulating activities as the functions of language in the brain. The human brains have acquired neocortices large enough to keep a great number of experiences in mind. Inevitably, human beings have had to

use the experiences in the brain efficiently and ingeniously. They would have accomplished the task through the language system (Sato, 2017, 2020). In the history of human beings, the features of language have worked advantageously. Seki and Hasegawa (2009) says that human beings are societal living things.

Semantics

Understanding meanings through language is done in precisely the same way as you understand the existence of (living) things and how they are there subconsciously and/or consciously seeing them in the outside world around you. Sato (1995) defines meaning as connections between Images (IMAGEs) in the brain and presents a language model, which is expected to show a probable way language exists in the brain.

A word consists of an *IMAGE* and *Image*s (Figure). An IMAGE is a linguistic sound, and an Image is *a picture* which "is imported" into the brain through all the sensory organs. Around 12 months old, certain Images become something special, or IMAGEs, in the language system in the brain of infants. Then the number of words increases in the language system (Sato, 1995).

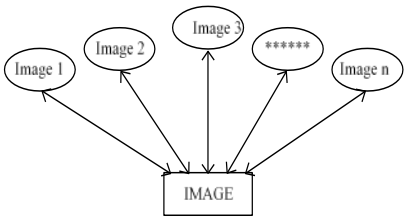

Figure. Relation between Images and one IMAGE. Adapted from "A model of language acquisition and the language system," by K. Sato, 1995, *Miyagi National College of Technology Research Reports*, *32*, p.61. Reprinted with permission.

As the number of IMAGEs increases, the verbs, part of IMAGEs, which have similar sentence patterns, other IMAGEs which are used as the same parts of speech and so on begin to reciprocally make networks, and then each network starts working as rather abstract grammatical items in the brain (Sato, 1995).

Understanding meanings in the brain is done in the same way as you understand the outside world seeing the world actually. With the lexical items which are composed as the figure shows, human beings actually describe the world which spread before their eyes and the world which is formed in CIW as a copy of the actual world. Therefore, the language system in the brain does not need more detailed abstraction than the networks show (Sato, 2013). Imitating the way they describe the outside world which they always see, human beings can acquire linguistic expressions to depict the world around them and the world which is composed in CIW. The grammatical items such as the relative pronouns can be acquired through the noun-centered expressions. Human beings can modify any nouns to describe the details of (living) things.

Human beings are able to visualize various scenes in the brain which are actually experienced and are just created by using the language system. As a dog begins to run in your brain when you form a picture of it in CIW and order it to run, any Images in CIW can be manipulated with the language system (Sato, 1995). Such scenes as spread before our eyes can be pictured on the cerebral screen. Any scenes can be created in CIW (Sato, 2013, 2017).

Such comprehensions of the actual outer world and the imagined worlds as mentioned above are thought as semantics in the brain. Human beings understand various things seeing the outer world actually. They also understand the worlds which are communicated through language in the same way as they understand the real world around them. It is semantics in CIW.

Grammar

Because almost all the information of grammar is conveyed through words (Sato, 1995), too abstract syntactic rules are not needed. Sato (2013) says that very simple rules can start the formation of sentences, and then make the word syntax go into action.

Because what are recognized through the sense organs or what remain in CIW are described through language system in the brain, sentences are automatically generated if one (living) thing is focused in on a cerebral picture (Sato, 2013).

The degree of abstractness of syntax, or grammar, is on the extensions of word syntax. What will you do when a student from abroad asks you about some usage of a word? You will remember some words which are supposed to conform the usage, show some examples, and maybe add some explanation. The syntactic, or grammatical, information

is contained in *the knowledge* of words in the brain.

What are discussed in Sato (1995, 2013, 2017, 2019, 2020 and so on) in consideration of the psychological reality of syntax, or grammar, are summarized in the sections above. To what degree are the discussions consistent with what the brain sciences have found so far?

Lexical items in the brain

The lexical knowledge lies scattered in various areas of the brain classified according to categories, parts of speech, and so forth: the so-called language areas, Broca and Wernicke, and other areas in the brain (Damasio & Tranel, 1993; Damasio, Grabowski, Tranel, Hichwa & Damasio, 1996). Damasio and Tranel checks where nouns and verbs are in the brain and concludes that the linguistic knowledge of lexical items and their semantic knowledge exist separately in the brain although they are close to each other in position, and there is a system to connect the items and the meanings. It reveals that the knowledge of proper nouns and some kind of common nouns is "in left anterior and middle temporal cortices" (p.4959) and "that of other common nouns is "in left posterior temporal and occipitoparietal cortices" (p.4959). It also says that that of verbs seems to be "in left frontal cortices" (p.4959). The suggestion that a lexical area and a semantic one exist in different places although the areas are close to each other and there is a system to connect the two areas is consistent with the structure of words presented in Sato (1995).

Verbs settle sentence patterns and the meaning of sentences. Pinker (2007) discusses the features of verbs. A sentence pattern used for a verb is set by the meaning of the verb and the verb decides the meaning of the sentence in which the verb is used. Verbs not only refer to their actions or states, but also provide the structures of sentences. As a frame of a sentence, they have slots for the other syntactic elements such as subjects, objects and compliments. In other words, when a verb is chosen for a sentence, sentences are generated naturally and automatically. The idea is compatible with the discussion that the syntax, or grammar, is included in the knowledge of words (Sato, 1995, 2013).

The mirror system

Mirror neurons were found at first in the brain of a monkey, and then the similar activities were found in the human brain; the system is known as the mirror system (Rizzolatti & Sinigaglia, 2009; Iacoboni, 2011). Mirror neurons were found in 1990 in Italy (Keysers, 2016). They were first discovered in the area F5 of monkeys. They react to a certain action both when a monkey does the action in person and when the monkey observes the action which others do. They are useful for understanding actions, the intentions of the actions and so forth. The area F5 of monkeys corresponds to the human area 44 in Brodmann's brain maps, which is part of Broca's area (Rizzolatti & Sinigaglia). Afterward, similar activities have been found in human brains. Because the activities of neurons cannot be recorded directly from them, they are called the mirror neuron system (Rizzolatti & Sinigaglia) or the mirror system (Keysers).

The mirror neurons

The mirror neurons of monkeys operate in the circuits through which the neurons link up to other parts of the brain and work like lexical items of motor performances. For example, the cerebral activities like a grasp would be understood in the relationship between the areas of a circuit which consists of the prefrontal cortex, the inferior temporal cortex, the cingulate cortex, the anterior intraparietal area, the area F5 and so forth (Rizzolatti & Sinigaglia, 2009, p.48). Part of the mirror neurons are activated both when a monkey does the action in person and when the monkey observes the action which others do. They are selectively linked to a certain motor performance. They are very much like lexical items of motor performances (Rizzolatti & Sinigaglia, p.58).

Actions and appreciation

The discovery of the mirror neurons can lead to an understanding about how the appreciation of behavioral intentions and the sympathy with others are achieved through the brain. Before the mirror neurons were found, researchers thought that first the information achieved through the sense organs were perceived in a certain area in the brain, then it was sent to another area, and finally the appreciation which is achieved through such activities in the brain activated some behavior. However, the discovery reveals that the cognitive appreciation and the execution of activities are fulfilled at the same area in the brain and by using the same cerebral circuit (Rizzolatti & Sinigaglia, 2009; Iacoboni, 2011; Keysers, 2016).

The behaviors which are not in the repertoire are able be learned by imitation. The learning forms new mirror

neurons or new parts of the mirror system. Because monkeys do not talk about themselves, on the one hand, the mirror system of monkeys does not have neurons equivalent for intransitive verbs. On the other hand, the human areas in the brain which are concerned with mirroring react to both intransitive and transitive activities. The fact is one of the features of the human mirror system (Rizzolatti & Sinigaglia, 2009).

Naturally, the human language system is also dependent on the mirror system. Although Rizzolatti and Sinigaglia (2009) concludes that the language system does not directly affect the cognitive appreciation and the execution of activities, quite the contrary, the language system undoubtedly develops and functions on the basis of the mirror system.

To appreciate others' behaviors themselves, the intentions of them and the emotional aspects is done by imitating them as own behaviors through the cerebral circuits, including motor areas. Knowing imitation-like systems in the brain is essential to understand the overall function of the brain (Iacoboni, 2011).

Pragmatic implicature

The difference between the meaning which is understand through the grammatical interpretation and the one that is implied in utterance can also be inquired into through the insight into the mirror system. Some problems of pragmatics (1983) explains the problem of pragmatic implicature discussing some problems of pragmatics. There might be discrepancies between literal semantic interpretations on the basis of grammar and the implicatures in utterances. In actual conversations, there are profound problems to be elucidated beyond semantic discussions on the basis of grammar. It must be an arduous problem in semantics (pp.752-764).

Implicatures in utterance also must be comprehensible when the discussions of compassion to understand the mirror system are applied to the problems of implicature. The researchers think that others' emotions can be read in no time at all through the mirror system and understanding feelings is different from compassion. Needless to say, emotions are got through watching others as well as emotional comprehension. In order to understand emotional phenomena, a number of factors have to be taken in account: collocutors, relationships with the collocutors, positions of the collocutors and so forth (Rizzolatti & Sinigaglia, 2009). That being the case, conversational implicatures are also explained in the same way; the idea that the information which is got through mirroring (the activities through the mirror system) is used with the situational information and, as a result, compassions appear in the mind, leads to understanding human sympathetic phenomena.

The super mirror neurons

The super mirror neurons work on the basis of the information about the awareness of oneself and others in order to understand only others' behaviors suppressing subconscious imitative desire through the mirror neurons. Mirroring not only causes you to comprehend what others are doing but also allow you to imitate what you are watching as you sometimes move your body while watching sports. The super mirror neurons which inhibit you from mimicking what others do have been found in the frontal area in the brain. It is to bring about a proper understanding of human behavior (Iacoboni, 2011).

The shared circuits

Ever since then, various mirror neuron-like neurons have been discovered in the brain: the neurons which respond to acoustic stimuli, emotional ones, etc. They have been thought to be functioned in such cases as understanding others. The cerebral overall activities similar to mirror neurons' are known as *the shared circuits*. The term, *the mirror neurons*, has been used in the discussions related to physical activities. The various cerebral activities such as acoustic and emotional ones which are similar to the activities caused by the mirror neurons have been found in the brain. To refer to the overall mirror neuron-like cerebral activities, the term, the shared circuits, has begun to be used in the research field instead of the term, the mirror neurons (Keysers, 2016).

The Hebbian learning rule

The Hebbian learning theory was originated so as to explain how the associative learning is realized in the human brain. Keysers (2016) borrows the rule in order to answer the question how different parts of the brain cooperatively fulfill various functions having connections with each other. The guiding principle is that if several neurons are excited synchronously, they combine with each other and begin to form networks (Keysers, p.145).

The Hebbian rule can explain the positive and

negative reinforcement of the neural connections properly. If there is a neuronal group: A, B, C, D and the neurons, A, B, C among them are coincidentally excited many times, the connection between A, B and C is reinforced and the neuron, D is eliminated from the network.

The rule is able to explain the formation of words. When an IMAGE (a group of linguistic sounds) and Images (a set of semantic experiences) are coincidently excited, words except verbs are made up. In the case of verbs, a group of mirror neurons is synchronously excited in addition to an IMAGE.

The syntax in the brain

The discussions in this paper indicate that the way language exists in the brain can be explained clearly. The mirror systems which have predicate-like function exist around the speech area in the brain such as Broca's and Wernicke's areas. Needless to say, they have immediate connections with word forms (IMAGEs). The forms are usually sounds, but in the case of sign language, they are signs. The other words are scattered in various places in the brain, gathering according to their features such as parts of speech and similar meanings.

The predicate-like neurons with IMAGEs organize sentences. They not only refer to movements and states, but also provide the structures of sentences. In other words, the linguistic knowledge such as the syntax is immanent in the predicate-like words. If the information given through perception or cognition of the world outside or that given through scenes pictured on the basis of the memories in CIW stimulates the predicate-like neurons, the stimuli invoked by persons and (living) things which make up the pictures in CIW draw out the other words from various areas in the brain and sentences are composed immediately and appropriately.

The hierarchical structure of language can be immanent in the basic cerebral motor program. The word orders and the hierarchical structures of language are sometimes discussed as features of language (Keysers, 2016). Pinker (2007) discusses that the word orders reside in the knowledge of the predicate-like words and Keysers (2016) says that the hierarchical structures inhere in the basic cerebral motor program (pp.92-93). The reality of the syntax and the way the syntax exists in the brain can be discussed and understood, considered with the understanding of the features of language discussed in Sato (1995).

Conclusions

Various topics which are related to the psychological reality of meanings, grammar and so forth have been discussed in my papers such as Sato (1995, 2013, 2017, 2019, 2020). This paper shows that the discussions are compatible with what have been found in the brain sciences. By synthesizing the linguistic model presented in Sato (1995), the discussions in my papers and what have been discovered in the brain sciences, the syntax in the brain and the reality of language in the brain can be understood clearly.

Notes

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