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The Function of the Limbic System: From the Perspective of the Cerebral Inner World

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The limbic system, or the old cortex, is usually treated as *a system*. However, the function of the system as a whole has not been discussed much so far. Parts of the system are usually talked about separately in relation to memory, emotion and so on. In this paper, the function of the system as a whole is discussed with the key words: the ordinariness, or the ordinary, and the extraordinariness. The ordinariness is a concept which consists of or can be replaced by a daily life, or the present, or the usual, or no novelty. The limbic system forms the ordinariness in the brain in relation to the neocortex. Human beings and the other animals have the ordinariness in common, and the ordinariness is important to live and survive in the actual world. The function of the cerebellum appears to be understood relatively well (Igaku-shoin, 2019). With the discussion in Sato (2017), in which the structure and function of the cerebral neocortex are talked about, the structural function of the brain as a whole can be finally understood.

Key Words: the limbic system, the brain, the cerebral inner world, amnesia, memory

Introduction

The structure and function of the cerebral neocortex are discussed in Sato (2017). The cerebral limbic system is taken up for discussion in this paper. The system is located at the center of the brain, or under the neocortex, and the brains of human beings and those of the other animals share the common and similar parts in this area. What do human beings and the other animals have in common? In the case of human beings, the lesion of the system causes some memories to be lost and the others to not be. It often results in anterograde amnesia. The regions which are related to emotion are omnipresent in the system such as the amygdala which would react to fear. A certain area of the hippocampus appears to deal with memories of spaces and locations. What function is postulated so as to explain all the facts? In this paper, the function of the limbic system in the whole brain is thought about in comparison with the functions of the other parts of the brain. The key words are the ordinariness and the extraordinariness. The ordinariness is a concept which consists of or can be replaced by a daily life, or the present, or the usual, or no novelty.

The limbic system

The limbic system is located between the neocortex and the midbrain (Carter, Aldridge, Page & Parker, 2012, p.57). The system is divided into several parts. Although what parts are included in it depends on the different opinions (Fukutake & Kawamura, 2012a), it is composed of the parts such as the limbic lobe [the cingulate gyrus, the subcallosal area, the orbitofrontal cortex, the temporal pole, the uncus of hippocampus, the hippocampus, the parahippocampal gyrus, and the isthmus of cingulate gyrus] and the subcortical nuclei [the anterior thalamus, the septum, the papillary body and the amygdala] (Watanabe, 2017; Fukutake & Kawamura, 2012a). The system is thought to be the old cortex. Almost all the animals from the lower animals to the higher animals share the similar structure of the limbic system, and the basic difference between the lower animals and the higher animals lies on how the new cortex develops in the brain (Tokizane, 1969).

The functions of the limbic system are said to be instinctive behavior, emotion, memory, autonomic nervous system and so forth (Fukutake & Kawamura, 2012a), and the system must be important in maintaining life (Watanabe,

2017). Although the parts mentioned above are bundled up and the system as a whole is named *a system*, each part is almost always mentioned individually. Regrettably, the function of the limbic system as a whole seems to seldom be discussed so far (cf. Fukutake & Kawamura, 2012a; Fukutake & Kawamura, 2012b). In almost all the cases, each part of the system has been discussed separately coupled with the problems of memory, emotion and so on (cf. Pinel, 2003/2005; Bear, Connors & Paradiso, 2007/2007; Carter, Aldridge, Page & Parker, 2009/2012; Kudo, 2013; Watanabe, 2017).

What kind of role, in the whole brain, does the limbic system play whose parts are treated as a system and referred to as the old cortex? In order to consider how the system as a whole works, each part is separately surveyed as the other studies usually do.

The hippocampus is usually discussed in relation to memory (Carlson, 2013; Kikuchi & Fujii, 2018).

The hippocampus

The medial temporal lobe which consists of the hippocampus, the parahippocampal gyrus and so on is central and important in fixing and refixing memory, especially in relation to episodic memory. When the human memory is discussed in the brain sciences, it is the case of H.M. that is almost always quoted. Carlson (2013) refers to the conclusions which Milner, Corkin & Teuber (1968) arrives at. Although it says that they are too rough, Carlson regards them as basics to consider when the memory system is discussed.

1. The hippocampus is not a place for long-term memory. It is also unnecessary in order to recall long-term memory.
2. It is not a place for short-term memory.
3. It plays a major part in converting short-term memory into long-term memory.

(pp.474-475)

The memories which are lost by the lesion around the hippocampus are those of the experiences which are gained within two or three years. The human memory is divided into short-term memory and long-term memory roughly. Short-term memory should be changed into long-term memory so as to remember experiences “semipermanently.” Some experiences would be stored temporarily in the hippocampus before they achieve stable status in the memory system as long-term memory. They are stored from for a few days to for several years. It depends on the nature of experiences. The memories which are kept temporarily may be lost before they get stable status in the memory system (Cater, Aldridge, Page & Parker, 2012). In the case of H.M., he remembered childhood experiences very well, but he did not remember his intimate acquaintance’s death three years before his surgical operation (Kikuchi & Fujii, 2018). It is said that it may take 10 or 15 years for some experiences to get the stable status (Carlson, 2013, p.481; Kikuchi & Fujii, 2018). In addition, the experiences with strong emotions are more memorable than the others (Cater, Aldridge, Page & Parker, 2012, p.158; Carlson, 2013). How to be retained in the mind is variable according to the quality of experiences.

The lesion of the hippocampus and the regions around it causes anterograde amnesia. In the case of H.M., he could not tell what he ate for lunch and even forgot having lunch itself thirty minutes later. He could not remember anything that he experienced after his surgical operation. A characteristic symptom of a person with the lesion of the hippocampus and the area around it is anterograde amnesia like H.M. (Kikuchi & Fujii, 2018).

The lesion of the hippocampus and the area around it does not cause short-term memory and implicit memories to fade away, and intellectual capacity also does not decline by the lesion. In the case of H.M., the outcomes of various tests indicate that his short-term memory is retained sufficiently. In addition, although he completely forgot carrying out his assignments and he did not explain how he carried out them, the learning effects were manifested in the tests such as mirror drawing and motor skill, which appear to need procedural memory (Kikuchi & Fujii, 2018).

The hippocampus is also concerned in the spatial memory. The bilateral lesion of medial temporal lobe, or depending on circumstances, the lesion only in the right medial temporal lobe, causes some problems to arise in the spatial memory, although the memory is not necessarily declarative. In the case of the patients who have the anterograde amnesia, they cannot follow their ways home properly because they cannot remember various landmarks, something characteristic and everyday matters in their environments in which they live (Carlson, 2013).

The hippocampus in the right hemisphere becomes active when spatial images are evoked in the mind. It is shown in the researches concerning taxi drivers in London.

The drivers need as long as about two years in order to get the taxi driver's license in London because they have to move there efficiently. When the drivers are asked to explain how they arrange the route in the city London in order to move their cars efficiently, the rear of the right-side hippocampus gets active. In addition, the research shows that, in comparison with ordinary people, the longer the drivers' experience is, the larger the part of the hippocampus is significantly (Carlson, 2013).

The amygdala

The amygdala plays a role in the aspects of the affect: the emotion and mood, and it assess likes and dislikes of experiences (Tomoda, 2012). It will concern all types of feelings because it is said that the activation of the amygdala in the left hemisphere leads to cheerful feelings (Carter, Aldridge, Page & Parker, 2012, p.169). However, in most cases, the importance of the amygdala is discussed especially with reference to fear and aggression. The aggression is thought to be part of reaction to fear (Bear, Connors & Paradiso, 2007).

With the lesion of the amygdala and the area around it, a person cannot read frightened expressions. With the problem, they cannot explain the faces expressing fear, even though being able to describe those expressing happiness, sadness and disgust in the same way as people do who do not have the problem (Bear, Connors & Paradiso, 2007). Although it has never come into common use, in the early twentieth century, the psychosurgery was performed in which the amygdala was excised from the brain. It was reported that the surgery was successful so as to control antisocial aggressive problematic behaviors (Bear, Connors & Paradiso, 2007). Thus the amygdala is usually discussed with reference to negative emotion such as fear.

It is also said that the amygdala works with the autonomic nervous system (the sympathetic and parasympathetic nervous systems) through the emotional reaction. When the amygdala reacts to severe psychological stress excessively, epileptic seizures may occur (Tomoda, 2012).

The insular cortex

The insula would get involved in mental representation with awareness. It is located in the inside of the operculum of the lateral fissure. It has a number of nerve connections with various areas in the brain and should integrate all kinds of information regarding emotional experiences. It ought to be concerned in such cerebral functions as the behavior control and the process of cognition through the conscious mental representation. It may be related to social learning because the representation of the emotions is induced by the empathy with someone else or the suggestions through language. It has been especially studied in relation to the aversion (Suzuki, 2012).

The cingulate gyrus

The cingulate gyrus plays an important role in the cerebral processes such as cognition, attention, and what the autonomic nervous system controls: the heart rate, the blood pressure and so forth (Watanabe, 2017). Carter, Aldridge, Page, & Parker (2012) refers to the functions of the cingulate gyrus. The anterior cingulate gyrus assesses the emotional significance of, especially, pain and how much caution should be given to the injury from which the pain originates (p.106). It works actively when the burdensome tasks are being done and when strong affection, rage, desire, and so forth are felt. It judges what other persons are feeling, and it responds to the feelings (p.124). It picks an appropriate behavior from the alternatives in accordance with a social background, and it modifies its intention. It remembers what are said to be taboo in a society (p.136). It works actively when innovative ideas are analyzed critically (p.168). It leads someone to understand a situation around them through connections with other persons (p.188). In sum, the region of the anterior cingulate gyrus with the area around it has to do with planning and handles matters in opposition to each other. The region senses hazardous things, transmits the ways of reaction to them and help commence actions such as escape (Tomoda, 2012).

The circuits and systems

All the regions in the brain do not function individually, but they work as parts of the circuits and the systems. The brain as a whole functions in the end. The limbic system also is not an exception. The severity of the memory disorder which is triggered by the lesion of the hippocampus and the area around it correlates strongly with the size of the lesion. The lesion in a certain part in the medial temporal lobe such as the hippocampal formation, the

entorhinal cortex, and the periolfactory cortex does not bring on a serious disorder. The severity is related to the size of the lesion (Kikuchi & Fujii, 2018).

The amygdala analyzes all the experiences, and it adjusts each related organ so as to trigger proper emotional reactions according to the results of analyses (Carter, Aldridge, Page & Parker, 2012). It integrates the memories of emotional experiences receiving signals from a number of regions in the brain (Manabe, Mori, Watanabe, Okano & Miyakawa, 2013). In addition, it directly receives main sensational signals from each sensory organ and gives off signals to the neocortex and many other structures under the cortex such as the basal ganglia, the hippocampus, and the hypothalamus (Kandel, Schwartz, Jessell, Siegelbaum & Hudsperth, 2014).

The insular cortex makes contact with many other areas in the brain such as the basal nuclei, the dorsal thalamus, the limbic system which consists of the cingulate gyrus, the amygdala, the entorhinal cortex, the hippocampus and so forth, and the various regions in the frontal lobe, the parietal lob and the temporal lobe. In addition, it has a large number of nerve connections in itself (Suzuki, 2012, p.1104).

The information on the discernment of emotions and their courses of actions is sent from the thalamus, the ventral striatum and the amygdala to the rostral anterior cingulate gyrus, and it joins up there with the suppressive signals which are transmitted from the frontal lobe and the prefrontal lobe (Carter, Aldridge, Page & Parker, 2012, p.126). The emotional reactions which the amygdala and so on give rise to are controlled by the signals (Carter, Aldridge, Page & Parker, 2012).

The Papez circuit

There are two circuits related to the limbic system, which are the Papez and the Yakovlev circuits (Fukutake & Kawamura, 2012a). Kudo (2013) says that the cingulate cortex and the cerebral cortex reciprocally exchange information through the Papez circuit, and it explains the circuit as below.

1. The emotional sensory inputs which the cerebral cortex receives send to the cingulate cortex.
2. The signals are transmitted from the cingulate cortex downward.
3. And then they reach the hippocampus and the amygdala through the entorhinal cortex.
4. The signals from the hippocampus are sent to the hypothalamus (the mammillary body) through the fornix. The signals to the hypothalamus evoke physiological emotional responses through the autonomic nervous system.
5. In addition, the signals reach the thalamic anterior nuclei through the mammillothalamic tract.
6. The signals are put back to the cingulate cortex finally.
7. Furthermore, the emotions which are aroused through this circuit are transmitted to the superior cerebral cortex, which leads to the emotional activities of higher order. (p.163)

The circuit is formed in the medial limbic system (Umeda, 2013). Kudo (2013) seems to explain the circuit in relation to emotion. However, it is often referred to as a circuit involved in the memory system at the moment (Umeda, 2013; Fukutake & Kawamura, 2012a). As it is discussed before, because emotions and feelings affect the ways of forming memory, obviously, the circuit has to do with both emotion and memory.

The Yakovlev circuit

It is known that this circuit is concerned with emotion (Umeda, 2013). The circuit is formed in the lateral limbic system: the amygdala → the dorsomedial nucleus of thalamus → the orbitofrontal cortex → the medial orbitofrontal cortex → the uncinate fasciculus → the frontal temporal cortex → the amygdala (Umeda, 2013). The signals from the frontal lobe have the function of controlling emotional behavior (Carter, Aldridge, Page & Parker, 2012).

The emotion

The amygdala or the limbic system analyzes all the experiences because no experience without anything emotional exists. Sato (2009) refers to the problem of the affect: the emotion and the mood. It explains that intense emotions are reactions to the experiences or the stimuli that seem to need some responses, and they are dealt with in course of time. The results of the handling are kept in mind as moods so as to handle similar stimuli simply and effortlessly from then on. In short, the experiences without intense emotion will be dealt with through the memories of moods.

Therefore, all the experiences or stimuli are assessed emotionally through the amygdala or the limbic system, although they can be subconscious processes.

The ordinariness and extraordinariness

The limbic system draws a distinction between the ordinariness and the extraordinariness, and it gives weighting to experiences or stimuli and shows what the memory system is to keep in mind immediately, what it is to put on hold and so forth. Recognizing or experiencing already-known things and persons may modify the memories of them (Carlson, 2013). Whether or not things and persons are already-known should be judged somewhere in the brain. Sato (2014) says, discussing the psychological time in the cerebral inner world (IW), that a feeling that things or persons are identical to those already-known leads to overwriting the memories. Modifying memories is explained as reconsolidation (Carlson, 2013, p.488).

A feeling that things and persons are as they are means the ordinariness. The concept of IW is proposed in Sato (2013) and has been discussed from different perspectives since then (Sato, 2018). Human beings have a copy of the actual world in the brain. IW is manipulated through language and so forth, and the manipulation is utilized in order for human beings to live well in the real world. To live means to live the present and is developed in the ordinariness (Sato, 2019).

The hippocampus gets involved in the consolidation of memory. Some memories may not be consolidated at all, others may be failing in process of time, and some may be consolidated firmly as long term memory. Kikuchi & Fujii (2018) says that, in order to form long-term memory, short-term memory has to be consolidated into long-term memory. Only when the experiences, or stimuli, which are in the brain as short-term memories are consolidated, they begin to be recorded in the brain as long-term memories. What type of experience can survive in IW? What sort of experience disappear in almost no time? Moreover, the experiences with strong emotions are kept in mind with facility as it is discussed above. The nature of experiences, or stimuli, can influence how fast or easily they begin to be memorized. It seems that these research topics have not been discussed much so far.

To live means to live the ordinariness for both human beings and the other animals, and the information of the ordinariness is important to live and survive in the actual world. As it is talked about above, the limbic system called the paleocortex is possessed in common among any animals: from the lower animals to the higher animals (Tokizane, 1969). Sato (2019) says that human beings have to accept the present as it is. Naturally, the other animals also have to do so. All the animals have the present, or the ordinariness, in common. It must be the reason all the animals hold the limbic system in common.

The unexpected, or the extraordinariness, has to be remembered, as a menace or a stroke of good luck, to survive in the actual world. It is the experiences, or stimuli, with strong emotions which have to be managed in any way and be remembered as moods for the occasions when the same or similar things happen in the future. It can explain the reason the stimuli with strong emotions are born in mind faster and easier than the ones without strong ones when they are experienced as the extraordinariness.

It takes longer time for the things or persons that are experienced in the ordinary situations in the ordinariness to be born in mind because they are not with strong emotions. To meet persons in the ordinariness whom people have not met before may seem to be unexpected occurrences but can be taken as the ordinariness. Because people often meet persons unknown to them, although the encounters themselves are new. To meet very famous athletes ought to be with strong emotions. The encounters can be memorized faster and more easily. How about the persons who happen to pass by? If a person is not noticed repeatedly, s/he cannot become an important figure in the ordinariness. In other words, isn't it practical that the persons who happen to pass by are kept in mind temporarily? It must be natural that the brain is equipped with the system through which the ordinariness and the extraordinariness are judged.

The hippocampus and the special memory

The ordinariness, or the daily life, unfolds in a certain space. The spatial information is brought from the parietal lobe through the entorhinal cortex (Carlson, 2013). The spatial information is to be essential in order to talk about the ordinariness. Various things, events and persons get linked to each other in the space of the ordinariness, and the relations among them give a significance to them. The worth of them are fixed in the space. The flow of the spatial information is able to be fairly understood discussed like this.

In order to understand the function of the limbic system, it must be necessary to stick to the precondition that the hippocampus is not the area for long-term memory. It is sometimes said that the amygdala and the hippocampus, which are parts of the limbic system, are regions for long-term memory: the amygdala keeps the memories of stimuli related to fear and triggers fright reaction (Kobayashi, Shigemura & Yoshino, 2018, p.816); The prolonged exposure is the therapy which reinforces the fear extinction circuit making the hippocampus repeatedly learn that a stimulus never leads to any aversive consequences (Kobayashi, Shigemura & Yoshino, 2018, p.817). The hippocampus and the amygdala are not regions for long-term memory, although they may hold some memories temporarily. Tomoda (2012), discussing the influence of maltreatment on the cerebral development, introduces a research which shows the memories of painful experiences are kept in the right cerebral hemisphere. Needless to say, because lesions in the limbic system do not allow long-term memory to function in the relations of the ordinariness, some problems would be expected to happen in a daily life, or in the ordinariness.

The neocortex

Sato (2017) discusses the function of the cerebral outermost stratum called the neocortex collectively. The input signals into each sensory organ such as eyes and ears begin to be treated in each primary sensory area, and the results of the analyses are integrated in each higher sensory area. The flows of signals are integrated more in the parietal association cortex and the temporal association cortex. The sensed experiences may be manipulated and modified on the cerebral screen by being compared with past memories, or experiences (Sato, 1995; Sato, 2013). The unconscious experiences may also be modified through the comparison. They are remembered in each association cortex in the end. The neocortex is an area for the analysis, utilization and remembrance of the sensory signals, or experiences.

The function of the limbic system

The limbic system forms a space of the ordinariness and helps human beings and the other animals to live in the actual world. It is between the neocortex which is a region for the higher cerebral function and the hypothalamus which causes the physiological reactions, and it functions as an intermediary between them (Kudo, 2013). The system and the neocortex are joined together by the Papez and Yakovlev circuits. The system receives sensational signals directly from each part of a human body. It gets the sensational information from both the body and the memory system and the control information from the neocortex, and it forms the ordinariness as a consequence. Without doubt, some stimuli can bring back some spatial information which has been experienced before and the space may be actually felt like the ordinariness. Combined with the discussions in Sato (2017), the activity of the brain as a whole can be understood totally.

The neocortex is the region for the analysis, processing and manipulation of the sensational information, or experiences, and the limbic system, in connection with the neocortex, which has similar structure with the other animals, is the area for forming the ordinariness, or the present, that is important to live and survive in the actual world. The system has been giving birth to the past. As a result, it has been bringing forth the future.

Conclusions

As it is discussed so far, when the cases which have been studied separately are discussed with the key words: the ordinariness and the extraordinariness, it is understood that the function of the limbic system as a whole is to form the ordinariness, or the place for a daily life and the present, in the brain. The function of the cerebellum appears to be understood relatively well (Igaku-shoin, 2019). With the discussion of Sato (2017), the functional structure of the brain as a whole is able to be understood collectively. The neocortex is the region for the analysis, processing and management of the sensational information, and the limbic system, which is deep in the brain and whose structure is shared by human beings and the other animals, makes the ordinariness, or the daily things and events. The ordinariness is also important for comparison with past memories in the brain in relation to the neocortex. It is necessary for human beings to live the present. As a result, the brain has always produced the past and the future with reference to the present.

Notes

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References

Bear, M.F., Connors, B.W., & Paradiso, M.A. (2007). *shinkeikagaku: noh no tankyu* (K. Kato, K. Goto, S. Fujii, Y. Yamazaki & K. Kaneko, Trans.). Tokyo: Nishimura Shoten.. (Translated from Neuroscience: Exploration the brain [3rd ed.], by M.F. Bear, B.W. Connors, & M.A. Paradiso, 2007, Philadelphia, PA: Lippincott Williams & Wilkins).

Carlson, N.R. (2013). *Carlson shinkeikagaku tekisuto: noh to koudo* (M. Taira & K. Nakamura, Trans.). Tokyo: Maruzen Shuppan. (Translated from Physiology of behavior [11th ed.]. by N.R. Carlson, 2013, London, UK: Pearson Education).

Carter, R., Aldridge, S., Page, M., & Parker, S. (2012). *bureinbukku mieruno* (T. Youro, Y. Uchiyama & M. Yuzaki, Trans.). Tokyo: Nankodo. (Translated from The brain book, by R. Carter, S. Aldridge, M. Page & S. Parker, 2009, London, UK: Dorling Kindersley).

Fukutake, T., & Kawamura, M. (2012a). taidan henenkei wo megutte zenpen [A colloquy: the discussion surrounding the limbic system Part 1]. *Brain & Nerve*, *64*, 1091-1096.

Fukutake, T., & Kawamura, M. (2012b). taidan henenkei wo megutte zenpen [A colloquy: the discussion surrounding the limbic system Part 1]. *Brain & Nerve*, *64*, 1131-1138.

Igaku-shoin. (2019). The cerebellum and cerebrum: The legacy of Masato Ito. *Brain & Nerve*, *71*, 1335-1408.

Kobayashi, Y., Shigemura, J., & Yoshino, A. (2018). shinteki gashougo sutoresu shougai no torauma kioku ni kakawaru mekanizumu [The mechanism concerned with traumatic memory of posttraumatic stress disorder]. *Brain & Nerve*, *70*, 813-820.

Kandel, E.R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S. A., & A. J. Hudspeth (Eds.). (2014). *Kanderu shinkeikagaku* [Kandel's neuroscience] (I. Kanazawa & Y. Miyashita, Trans.). Tokyo: Medical Sciences International. (Translated from Principles of neural science [5th ed.], by E. R. Kandel, J. H. Schwartz, T. M. Jessell, S. A. Siegelbaum, and A. J. Hudspeth, 2013, New York, NY: McGraw-Hill).

Kikuchi, H., & Fujii, T. (2018). Sokutouyosei kenbo [Medial temporal amnesia]. *Brain & Nerve*, *70*, 783-794.

Kudo, Y. (2013). *motto yoku wakaru! noh shinkeikagaku: yappari nohwa sugoinoda* [To understand it more. Neuroscience: Anyway, the brain is great]. Tokyo: Yodosha.

Manabe, T., Mori, H., Watanabe, M., Okano, H., & Miyakawa, T. (2013). *noh shinkei kagaku irasutoreiteddo: bunnshi saibo kara jikken gijutsu made* [Neuroscience illustrated: From molecules and cells to experimental technologies] (Revised 3rd ed.). Tokyo: Yodosha.

Milner, B., Corkin, S., & Teuber, H.-L. (1968). Further analysis of the hippocampal amnesic syndrome: 14-year follow-up study of H.M. *Neuropsychologia*, *6*, 317-338.

Pinel, J. P. J. (2005). *baiosaikorojii* [Biopsychology] (K. Sato, K. Wakabayashi, M. Wakui, & N. Asukai, Trans.). Tokyo: Nishimura Shoten. (Translated from Biopsychology [5th ed.], by J. P. J. Pinel, 2003, New York, NY: Pearson Education).

Sato, K. (1995). A model of language acquisition and the language system. *Miyagi National College of Technology Research Reports*, *32*, 59-71.

Sato, K. (2009). The mind. *Miyagi National College of Technology Research Reports*, *45*, 23-27.

Sato, K. (2013). What do human beings talk about? : In the search for the psychological reality of syntax. *Sendai National College of Technology, Natori, Research Reports*, *49*, 7-10.

Sato, K. (2014). Psychological time in the Inner World. *Sendai National College of Technology, Natori, Research Reports*, *50*, 11-15.

Sato, K. (2017). The cerebral structure and the Inner World. *National Institute of Technology, Sendai College, Natori, Research Reports*, *53*, 1-6.

Sato, K. (2018). Clinical psychology and the Inner World. *National Institute of Technology, Sendai College, Natori, Research Reports*, *54*, 1-5.

Sato, K. (2019). Grammar and the Inner World: Thinking about the psychological reality of grammar. *National Institute of Technology, Sendai College, Natori, Research Reports*, *55*, 1-6.

Suzuki, A. (2012). shima no joudo kino [Emotional functions of the insula]. *Brain & Nerve*, *64*, 1103 -1112.

Tokizane, T. (1969). *medemiru noh: sono kouzo to kino* [Brain illustratrions: its structure and function]. Tokyo: University of Tokyo Press.

Tomoda, A. (2012). *shinpan iyasarenai kizu: jidougyakutai to kizutsuiteiku noh* [The revised edition, uncurable wounds: child abuses and the brain which has been gradually wounded]. Tokyo: Shindan to Chiryo Sha.

Umeda, S. (2013). dainoh henenkei [the limbic system]. In T. Fujinaga (Ed.), *saishin shinrigaku jiten* [The newest phycological encyclopedia] (pp. 495-496). Tokyo: Heibonsha.

Watanabe, M. (2017). *noh shinkei pedia* [The brainpedia]. Tokyo: Yodosha.