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A detailed account of language processing in the brain with focus on semantics and syntax

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A B S T R A C T

The present study touches on underlying neurological aspects of linguistic competence. In so doing, the researchers briefly review the relationship between neurology and linguistic theories addressing the development of language. Obviously, the respective findings about neurological language disorders could be helpful in determining the most dependable theories of language. To this end, a short account of biology, and evolution of language and its monitoring in hemisphere are provided. Then, the characteristics of language disorders (such as aphasia) in terms of language structures and the corresponding lesions to the brain sites are reviewed. Furthermore, syntactic and semantic approaches to the study of neurological language disorders along with respective linguistic principles are explained in some details. Finally, we arrive at the conclusion that the specific signs and symptoms associated with disorders are predictable drawing upon the language structures in the brain and linguistic theories.

Introduction

A group of acquired injuries called aphasia are known as the consequence of a bunch of local disorders in the brain due to stroke, brain tumor, head injury or bleeding. Neurolinguists have been interested in the localization nature of such lesions and their special relationship with language disorders due to the possibility of finding exact position of language functions and activities in various areas of brain which can be very useful in the treatment of patients.

The damage to various areas of brain leads to different kinds of language disorders the most widespread and known ones are Broca aphasia and Wernicke aphasia which were discovered by Broca and Wernicke in 1860s and 1870s, respectively. In Broca aphasia, patients typically have difficulty in production due to the frontal lobe of left hemisphere injury and in Wernicke aphasia they have difficulty in comprehension due to temporal lobe of left hemisphere injury.

Following these scientists, other people like Geschwind and Lichtheim, found that the macro language activities are monitored in certain brain areas (Shapiro, 2003) and introduced it as the theory of localization or language as activities. According to these two views, speech production depends on motor brain areas near Broca and speech comprehension depends on the auditory perception area near Wernicke.

Although the localization concept of language function has been considered so far, it seems it does not enjoy a good theoretical adequacy, particularly of linguistic theory, due to the lack of a plausible linguistic theory so that the construction and development of an exact brain linguistic mapping confronts some challenges.

Noam Chomsky's revolution in providing various linguistic theories could contribute researchers in neurological studies related to language activities in brain. The exact syntactic categorization of language led linguists to analyze the speech of aphasia patients efficiently to perceive that the traditional view (Broca and Wernicke aphasia) about disorder in comprehension and language production is unable in the accountability of the concerned problems. For example, among Broca aphasia patients, we can see that language production problems reflect in language comprehension. For instance, people who are not able to produce morphosyntactic affixes can't understand those structures too. These grammatical deficiencies extend to sentences level so that in Broca aphasia the most emphasis is on semantic, contextual features of input that help language comprehension. Consequently, problems in language production among patients suffering from Broca aphasia are to some extent because of the faulty syntactic analysis and processing, but at the semantics level patients have acted normally (Swinney, 2002). Otherwise, in Wernicke aphasia it has been noticed that patients have normal syntactic function but from semantic inference perspective suffer from disorder and often produce nonsensical discourse and speech (which are often grammatically correct). Therefore, it can be seen that Wernicke area semantically and Broca area syntactically are often active.

More researches on information obtained from patients suffering from cerebral lesions, which have benefited from complicated neuroimaging technologies, also showed some deficiencies even in attributing linguistic levels of representation to brain (Grodzinsky & Friederici, 2006**)**. New researches' results indicate inefficiency of current linguistic theory. Intensive cross linguistic studies on aphasia patients and other language disorders by EEG (electro encephalography), MEG (magneto encephalography) and FMRI (functional magnetic resonance imaging) on healthy brains indicate that areas related to syntactic processing haven't been in Broca area and no semantic processing in Wernicke area. These findings paved the way for neurolinguistic procedures in studying the relationship between brain and language. Recent examinations by researchers on information achieved from brainimaging and aphasia patients, in order to develop a linguistic mapping in brain, have provided a very comprehensive image than past (Swinney, 2002). According to these findings, syntax hasn't been limited to one area of brain but it has subcomponents with precise functions in various areas of brain. In this new procedure even some sectors of right hemisphere are involved in syntactic processing (Zurif, 1995).

The deficiency of neurologic researches by PET (Positron Emission Tomography) and FMRI is related to the subject that in most of them the researchers haven't been aware of new linguistic theories and their emphasis has been greatly on individual words or written language presented visually. The linguists and neurolinguists cooperation is increasing everyday and the result is more success of both groups in studying such diseases.

While blood circulation is measured in haemodynamic techniques, neurons' electric current is evaluated in electrochemical methods like EEG, which is done by placing some electrodes on the head. EEG has a high temporal resolution (very higher than FMRI) so it is able to measure brain electric activity very quickly. Many researches done by EEG include ERP (Event-related Potential Technique) techniques in which some electric currents and changes are recorded in relation to language external phenomena (like inputs at the sentences or words level). From some researchers' viewpoint, unlike FMRI studies, many of researches are designed by the use of ERP by linguists and not neurologists the mentioned reason is cheap method and instrument. In this connection, researchers also have performed linguistic processing by ERP. It should be mentioned that N400 waveform is considered in relation to semantic processing while N600 and LAN wave are considered in relation to syntactic processing (Shapiro, 2003). One of ERP's limitations, especially, in researches on developing linguistic mapping in brain is inability of this technique in showing a place from neural tissue where electric signals are created.

In MEG the produced electric current is measured by active neurons, but it uses only some signals that come from cortex area near the scalp surface. This method can show spatial temporal with a high resolution. It is used to compare semantic and syntactic variables and connecting them to neural net activity.

Now, in respect to deficiencies and strength of these imaging methods it can be concluded that the most successful method is applying a combination of these methods. In fact, the most efficient procedure as a three pronged approach is using imaging techniques, studying created lesions in brain and designing research questions based on an acceptable linguistic model. But such a method is not always used and according to Grodzinsky, neurologist scientists who use new imaging technology in language study, at first, couldn't benefit from the whole data related to aphasia from Broca period. On the other hand, developed theories on language have not taken advantage of theoretical adequacy. For example Petersen *et al.* (1990) used PET and FRMI in order to see present differences in brain activity due to language production and comprehension, but they have achieved the same results as Wernicke in the past century. They have considered language holistically in this set of studies and have used a range of various linguistic motives. Thus some contradictions between findings of various methods can be noticed. Such anisotropical findings, anatomically, are the results of an incomplete definition of a theoretical level which have been used by the researchers. The linguistic actions and/ or reflections are not probably the appropriate units of analysis in exact specification of the relationship between language and brain, the possible reason is absence of anatomical compatibility among past studies in which inappropriate unit of analysis is chosen.

A group of scientists, by the use of FMRI and another group by MEG, FMRI and PET, have tried to separate the syntactic processes from semantic processes and find linguistic subsystems in brain, but these studies also have had a considerable anatomic compatibility that indicates inadequacy of the fundamental linguistic model of this group of researchers (a model in which language is converted to subsystems accordingly). Of course, in these studies anatomical correlations have had other reasons: the language is not monitored in a specific place in the brain (Swinney, 2002) and is scattered in all parts of the brain; another reason is the difference in the place of the linguistic functions viewpoint among individuals; and finally, the photographic tools are not reliable to 100 percent. With all of this, the main belief is that the experiments have not tested whatever has been expected to be tested and the reason is the unpurified view of language structure (Grodzinsky and Friederici, 2006**)**.

Grammatical systems, whether syntactic, semantic, phonetic or lexical, are the best unit of analysis and the information obtained from aphasia cases suggests that verbal shortages are resulted from particular rules of language. For example, people suffering from Broca aphasia don't have problems regarding inflection agreement but they face problems regarding tense inflections. Disorder in verbal conception also has selective form regarding syntactic and is related to particular rules. In Broca aphasia, it is difficult to comprehend transformational sentences such as passive structure or objective relative form whereas non-transformational sentences are comprehended completely (Zurif, 1995). These findings resulted in the presentation of Trace Deletion Hypothesis (TDH) according to which in receptive language, individual's brain suffering from aphasia is not able in transformational calculations since related mechanisms embedded in Broca area are damaged. Comparative studies among different languages such as Chinese, Dutch, English, German, Hebrew, Japanese and Spanish all approved this hypothesis. English aphasia patients are able to comprehend and interpret active sentences with SVO structure but in Japanese aphasia patients the condition is more complex because in Japanese language there are two active sentences one is verb+ object + subject (VOS) and the other is verb + subject + object (VSO).

These two forms of sentences are identical regarding meaning. The only difference is that the latter has transformational form as the Trace Deletion Hypothesis predicts. The Japanese aphasia patients perceive the first form but not the latter accurately. Such findings led scientists to the fact that there is a systematic relationship between subcategorical syntactic theories and brain areas that is particular aspects of universal grammar knowledge are monitored in particular areas of the brain. These attempts resulted in FMS (Formal Syntax Map) appearance in 2006.

There is a very interesting difference in the perception of two syntactic rules among Broca aphasia patients; they comprehend sentences which include verb movement and are able to notice the inobservance of this rule. But this is not true about the noun phrase movement and they are not able to notice the inobservance of this rule about noun phrase. In this regard some considerable studies have been conducted on neurologically healthy people and aphasia patients in various languages including English (Zurif, 1995). In contrast to anatomically vague results obtained from primary brain imaging studies which aimed at finding language activities' location in brain, the results of such studies which were conformity of grammatical rules with various locations in brain have been more similar and uniform. For example, noun movement activates left inferior frontal gyrus area and superior temporal gyrus while verb movement activates left superior frontal gyrus and middle frontal gyrus.

Therefore, it is noticeable that although FSM is not complete yet it can reveal fairly precise representation of the relationship between language and brain at least in syntactical aspects. It must be known that syntax doesn't function separately and one of the main neurologists' challenges is how to separate and analyze various existing operations in language while language is processed in brain.

How can we make sure that active brain areas are not doing anything while processing syntactic operations? We can omit particular areas such as neuron tissues related to controlling movement mechanisms of the vocal cords at the time of speech via verbal language and sign language contrast. But separation of various related processes at the time of verbal activities is much more difficult. The same is also true about other verbal subsystems such as semantic. For example, Patterson *et al.* (2007) regarding Wernicke aphasia, Caramazza believes that most of imaging studies are not able to distinguish between accessibility to auditory lexical forms and finding lexical forms location in meaning because lexical production or recognition is unconscious activation of its meaning.

According to researchers' findings to make FSM more efficient or to present the brain location of semantics, lexical and acoustic it is better to identify areas of brain that are involved in processing and parsing. For this reason, Language Processing Map (LPM) comes to exist. While FSM identifies syntactic knowledge, LPM is tracing those areas of brain which participate in syntactic process. In fact LPM hypothesis is FSM complimentary, just the way as grammatical subcategories of language knowledge have individualized and localized form. Likewise, the subcategories of verbal processing systems are recognizable and tractable neurologically. In these studies four main imaging techniques are used: FMRI and RET for finding brain monitoring area; EEG and MEG processing for measuring existing time scales. There are three distinctive processing phase according to this model: the first phase is calculating phrase structure according to lexical categorization, the second phase identifies dependency relation between structures and the third phase is, in fact, collecting all existing syntactic information (Gregory, 2009). In sum, the first phase activates frontal operculum that is located in left IFG near posterior part of Broca area and anterior STG, the second phase is related to Broca area BA 44/45 and the third phase with activity in left and right posterior STG. In addition, the information resulted from diffusion tensor imaging implies that these areas are related structurally that is an evidence in approving Frederici hypothesis (Zurif, 1995).

Frederici and Grodzinsky attempts, in finding brain language map regarding syntactic knowledge and syntactic processing, indicate outstanding advances in the comprehension of the relationship between language and brain. In spite of all these noticeable advances, existing knowledge on brain's operation in general and the relationship between language and brain in particular is very limited compared to our knowledge of other parts of body. From many aspects, our knowledge regarding the relationship between language and brain is less than our knowledge about the relation between brain and other physiological operations such as visual system. It is mainly because of the peculiarity of language to the human species however the brain itself is not so. Conducting different kinds of aggressive experiment on human being is not possible while ethical considerations are very important. Regarding nonverbal cognitive operations such as audio, visual, movement reflex, etc there have been many studies on the other animals that is applicable to the humans but language is a specific subject. From the birth, some parts of language exist hard wired in our brain called principles and is universal but other language aspects develop via environmental stimuli called parameters. In studies related to language and brain, neurologists face many limitations.

Existing evidence suggest that lingo neurologists are on the correct path in the determination of the language map in the brain and if such a map is identified not only our knowledge of the relationship between brain and language increases but also our perception of brain operation will expand.

Rehabilitation of individuals suffering from Aphasia and even other people suffering from other brain disorders can help us in the empirical testing of abstract theories to a great extent. According to Chomsky (the father of the modern linguistics) the primary aim is to uniform language doctorine, brain doctorine and other viewpoints. Definitely, the more interaction between these two scientific fields, the more real theoretical unity can be achieved.

The aim of the present study is specifying the representations and cognitive processes in brain which can answer four main questions:

First, what parts, areas and neurons are involved in the brain during verbal operations?

Second, in what stage of production or comprehension are these processes and representations activated?

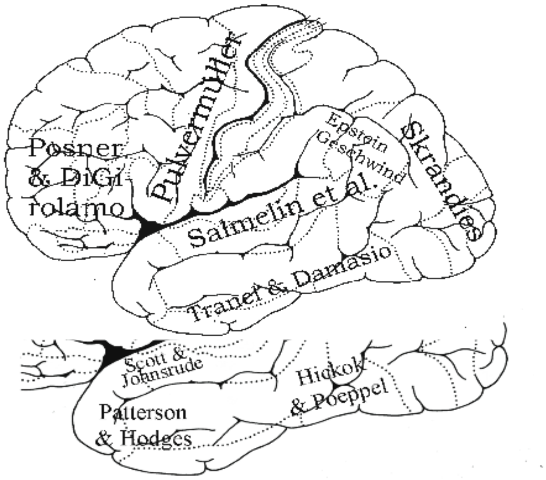
Third, what neuronal circuits are the basic foundations of verbal representations in brain and what spatiotemporal neuronal activity pattern do the processes follow?

And finally, for what reasons are the located representations and processes in particular areas of the brain at a special point of time (whether in production or comprehension) activated?

In so doing, the focus of attention will be on new progress in the field of representations and language processes in brain from the viewpoint of time and place. Definitely semantic, syntactic and phonetic aspects of language must be analyzed, however; due to limitations, the researchers just consider the first two aspects.

Semantic representations and processes in the brain

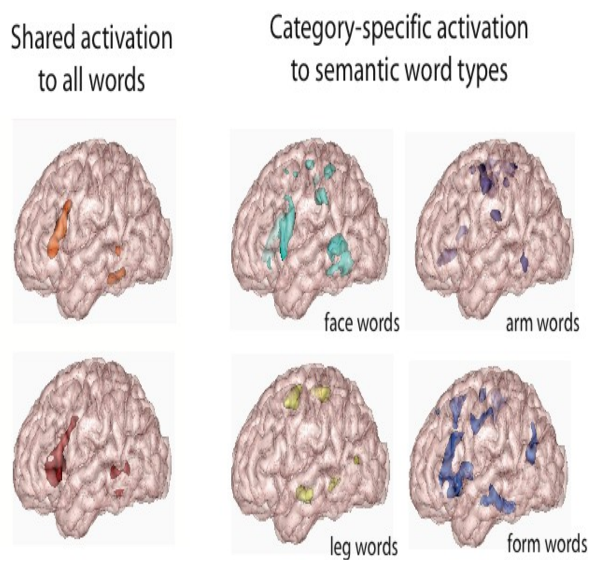
Once in neurolinguistic science, all scientists tried to find the monitoring location of the main language processing models in brain. Regarding semantic processing, until 1999, most believed that particular parts of left hemisphere are involved in word meaning process (Guido, 2008). Even later consensus was that temporal lobe is the foundation of meaning operations, for example (Alex, 2007) stated that lexical interface is somehow the connector of meaning and phonetic representations in the middle temporal cortex or Chao *et al.* (1999) asserted that anterior part in superior temporal gyrus is the location of meaning interface and at last Simmons *et al.* (2007) in their studies on mental illnesses concluded that temporal pole is the main area of semantic processing.



The figure shows this kind of varying orientations concerning language semantic placement in brain. As it is obvious from the picture, different scientists considered various cortical locations concerning meaning and form. The main problem in these studies is that in spite of certain evidence in approving the importance of cortical areas in semantic processing at least in temporal and frontal lobes, no one can reject the role of other areas. This is possible only when a particular area of cortical works as the keyboard of semantic monitoring. Although semantic processing indicates unity of received information from sensory modalities, this unity can be calculated locally between adjacent neurons that a mass of interacting neurons distribute them and for this reason there is no need to find a unitary semantic area.

Second main problem regarding unitary semantic procedure is semantic category specificity. In many cases, lesions do not damage all kinds of words to the same extent and depending on lesion's location; specific category of our lexical knowledge is damaged. Meaningful differences between semantic kinds such as animals' names versus tools and objects' names due to the injuries in frontal and temporal cortex and also processing differences between these kinds in patients affected by semantic dementia have been reported (Pulvermüller *et al.*, 2009).

Uniformity consideration of common lexicosemantic processes and semantic category specificity processes which is obvious in interaction between cortical areas can be solution of this divergence of views (Simmons *et al.*, 2007). Finding precise location or in a better word the distribution of specific and common circuits of semantic category specificity in recent neurological studies has been considered a lot.



The figure shows information related to approximate placement of semantic category specificity circuits. Their difference from common activities of brain related to the meaningful written word stimuli can be noticed.

According to the figure on the left, cortical areas are activated by all words to the same extent while there are other areas which are activated by semantic categories of words (on the right), for example reflexive words related to face (lick), hands (lift up) or legs (kicking) and the words showing geometric shapes such as square Simmons *et al.* (2007) areas that are often active for all species of words indicate the distribution of circuits in processing general information of lexicosemantic While there are other areas with active wider distribution which belonged to special semantic species and function as an indicator of the semantic distribution circuits with category specificity. So practically, most of the words are activator of the middle and inferior-temporal areas that involved in processing visual information about objects. This fact is not surprising since in languages such as English most words have noun form which are known visually. Words related to animals and objects and the related concepts in both brain hemispheres are the activator of inferior-temporal and middle temporal areas (Moscoso *et al.,* 2006) (Miceli *et al.,* 2001). And words related to objects denoting color or spatial shape are activator of distinct but overlapping regions of bursiform, parahippocampal & middle temporal gyri (Kiefer, 2008), (Pulvermüller *et al.,* 2008) and (Barsalou, 1999). Inferior-temporal region from pole to temporo-occipital junction represents a range of semantic distinctions. Injuries in this region lead to semantic category specificity degradation and also semantic impairment with category specificity. For example, injury in the rostro-mesial temporal cortex in the left hemisphere, under part of it which is lexical processing related to color activated, defects the knowledge of objects color, particularly (Lakoff, 1987).

Of course, the temporal lobes are not the only key areas in semantic processing, and words with affective-emotional connotations can activate emotional amygdale, posterior cingulated cortex, and insular structures. Words related to smell activate olfactory cortex with limbic structures (Moscoso *et al.,* 2006) and words related to sound activate superior temporal lobes (Boulenger, 2009) and verbs related to actions activate Motor and premotor cortex area in a way that the body part of that action plays a role as words in the activation of somatotopic in the motor strip **(**Pulvermüller *et al.,* 2010). Accordingly, words such as pick and kick activate the areas where they are active at the time of shaking a finger or toe.

The overlap between active brain areas is not complete at the time of motor performance and word processing, creating somatosemsory input that activates somatosemsory postcentral which in turn transfers centroid to the left and toward parietal lobe. A study authenticated semantic somatotopy and abstract expression processing like “grasp the idea, kick the habit which is somehow similar to compositional view about sentence abstract semantic structure in which the meaning of the term is very influential (Lakoff, 1987; Barsalou, 1999).

The important point is that motor activation seems to be very important parts of the cortical semantic processing index. Motor system injuries damage action related words processing, especially; verbs related to action and the related concepts (Simmons *et al.,* 2007; Miceli *et al.,* 2001). In healthy people, magnetic stimulation lower than the motor threshold of areas related to hand and leg in left motor cortex facilitates processing of especial terms related to hand and leg (Pulvermüller *et al.,* 2008). These findings represent the causative role of motor system in semantic processing of expressions and action words.

The result of the above mentioned materials is that the amount of the specificity of the meaning in the brain areas is much more than what it was supposed to be. This is interesting from linguistics’ viewpoint since some semantic features of the words are observable because of the resulting brain response. Theoretically, it is important that semantic areas in the brain are not predictable based on the shear brain theory.

These materials are strong evidence that confirms an underlying distributional model. However, searching a unitary meaning center has resulted in many discrepancies. It is possible for the semantic integration to be related to one area of the brain at the most abstract levels. The meaning center can be described as: the integration of the brain areas that are critically related to special categorical processing, and the tendency toward more important role of temporal cortex among researchers may be related to their excessive attention to object's nouns and concepts. It must be considered that our awareness of most of the objects is visually; therefore, the interference of processing the nouns of the objects in the inferior temporal area is natural. Even regarding abstract nouns and sentences, different activated areas are recorded by the researchers (Boulenger *et al.,* 2009). In turn, it raises the question whether categorical specialty at abstract semantic levels is true (Pulver and Hauk, 2006). Based on a view, more abstract semantic representations are gradually created in temporal & frontal cortex that are the consequence of sensor-motor activity (Barsalou, 1999).

Based on unitary view, the exact distribution of semantic circuitry with special category depends on the type of the meaning. The most important brain areas related to meaning are near left-perisylvian language cortex, especially inferior-frontal and superior-temporal gyrri, together with insula are its cornerstone. Semantic circuitry related to actions and objects are related to sensory-motor areas and abstract semantic circuitry is created around these sensory-motor spots which are anterior temporal and prefrontal cortex. Of course, differential laterality is related to processes and lingual representations and semantics. Because of some of left perisylvia cortex features, linguistic circuits are usually lateral, but semantic circuits are symmetric in both brain hemispheres (Lakoff, 1987). Although recent evidence in confirming semantic circuits with special category underlines basic brain perception, it is still under criticism. Caramazza group believe that during the action verbs process the motor activities may not be related to semantic processes rather in the form of epiphenomenon, it may be related to brain images taken from reserves. A new view believes that there exists a semantic operation from motor system that complements an abstract symbolic processor. It is similar to Pattersen’s view in which a kind of semantic hub exists as a complement of semantic circuitry with special category that is distributed in a vast area.

There is a false inference regarding the role of sensory-motor circuitry in semantic processing according to which just one source of semantic knowledge is considered; however, it is not acceptable. Our hybrid knowledge of the words that occur orderly in the sentence and discourse context is the index of semantic knowledge. For example, regarding the most prominent word relating to color the word strawberry (in European culture) comes to mind. Hybrid features of the words not only stimulate the classification of the words in the form of syntactic versions but also result in distinctions in semantic boundaries that distinguish samples of the objects and the actions. A mechanical neurobiological approach explains the store of the word-word bilateral underlying communication by the same mechanisms used in the store of word-outside world bilateral communication in the neuronal connections among perisylvian and sensory-motor lingual cortex (Pulvermüller *et al.,* 2010). New Neuronal imaging reveals semantic representations of constituent words and general structures cooperation at the time of semantic processing of abstract idiomatic sentences.

Of course there are some questions about cortical focal positioning of the abstract phenomena. In a recent study, researchers found that there is a set of different smaller areas near each other in left middle temporal area that generally react to words)-(53/-49/-1) and in this way help discourse-semantic phenomena and special semantic subcategories of action verbs (relating to -49/-51/-9) (Pulvermüller *et al.,* 2010). The results obtained from this kind of studies reveal the differential role of temporal &frontal areas in semantic processing although future research can determine various lingual roles of activating middle temporal gyrus in words and sentences processing.

Syntactic processing

Another important issue in the study of brain science is whether syntax depends on the combinatorial rules or it is fully describable based on the sequential probabilities. Linguists' view regarding the existence of the syntactic rules and universal principles of grammar confronted the approaches that use systematic probabilistic location in neural networks and statistical calculations without any symbolic rule like representation. The sentence "build a sentence from a noun and a verb" is a discrete combinatorial mechanism at the abstract level. Now the question is whether we can assume such separate rule like phenomena rather than probabilistic role finding as significant at neurological level?

Experimental test for the existence of the rule like mechanisms is possible when dissociation of probabilistic mapping and the application of the rule exist. Instances of this are sentences that are grammatically correct but they are rarely used in daily use of the language. As it was pointed out ungrammatical strings result in more powerful brain activities than common grammatical ones. Since this neurophysiologic difference is observable even at the time of recording identical discourse strings of words and when people don't pay attention to discourse stimuli, it can be said that some brain activities which relate to grammar are automatic (Barsalou, 1999). Now, whether rare ungrammatical strings create a brain reaction which is not different from usual grammatical strings or gradual probabilistic differences between strings of words that are reflected in the neurophysiologic reaction of the brain relate to two approaches of all-or-nothing and probability mapping. Research evidence reflects rule theory, that is, regardless of sequential probability of structural words, the response of the brain to rare ungrammatical strings of words is more powerful than the response to grammatical strings. It is noteworthy that neural approach without discrete representations can be changed and developed by implementing nonlinear shapes in neural network. In this regard, it can be said that significant evidences of discrete combinatorial rules are in the left perisylvian circuits of the brain.

Conclusion

Based on the findings pointed out in this review, it can be said that there are some discrepancies in related methodologies. Future research may result in more unified findings by applying unitary linguistic theories and high technologies.

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