

Article

Difficulty of Energy Expenditure of Brain When Using Written Speech

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Abstract: The structural organization of the brain matures between 16 and 22 years old when spontaneous contradictions in individual behavior appear with the greatest frequency which is caused by the duality of human consciousness based on the early maturing instinctive-hormonal centers of the limbic system and the late differentiating neocortical fields of voluntary thinking. When creating a written speech, limbic and cortical mechanisms of motivational control are used and individualize the resulting text. Personalization of writing meaningful texts is enhanced by the variability of brain structures involved in this process. We examined evolutionary morphofunctional systems to evaluate their biological value. Depending on individual priorities and motivational choices, written composition was carried out in two strategies. The first was the most general principle of saving the energy expenditure of the brain during any voluntary activity. The second was the mobilization of cortical centers with extremely high energy costs. To identify these differences, a pragmlinguistic analysis technique was developed in this study, supporting both strategies.

Keywords: Brain, Written language, Pragmlinguistics, Broca's area, Wernicke's area

1. Introduction

Speech functions operate in archaic hominids soon after the appearance of bipedalism and the development of hunting methods that make non-verbal communication difficult. This finding has been confirmed by numerous studies of microcephalics with non-genetic forms of brain development arrest. With a brain mass of 400–450 g, words can be pronounced, and simple but meaningful communications can be possible. This is confirmed by the study of the evolution of the hominid brain and by the analysis of cases of microcephaly not complicated by severe genetic pathologies [1]. It took several more million years for humans to be able to write since this complex human function of the brain requires the development of fine control centers for the control of the fingers and associative prediction in the synthesis of complex reasoning and their sequential presentation. Additional cerebral difficulties in using written language arise to convey the meaning of the text to the target audience. To predict and model the understanding of the future reader, an author uses all the associative analytics of the brain at his disposal. Individual reconstruction of still-planned events forces authors to use the energetic or rational potential in the creation of texts [2,3]. The earliest work on energy metabolism showed that brain metabolism underlies behavior. With the deviations in the energy metabolism of the brain, significant changes in written speech occur [4]. Consequently, the analysis of brain metabolism shows unambiguous results, which vary and are reflected in an individually written text [5].

On the surface of the cerebral hemisphere, there are a dozen groups of fields and subfields of the neocortex that are involved in the motor control of written speech (Fig. 1(a)). The hand and fingers take part in this most difficult task. Both the mechanics of writing and the planning of a sequence of movements depend on their coordinated actions. For this reason, the motor cortical area of the fingers is connected closely with sensory or sensory subfields more caudally. They transmit signals from different somatic receptors in the skin, ligaments, and tendons of the hand. The epistolary genre involves the use of one hand, which relates the area of maintaining muscle tone and controlling the coordination of asymmetrical movements. In this process, the area of the neocortex participates inevitably to coordinate the movement of various muscle groups involved in writing (Fig. 1(a)). In the area of the hemisphere under consideration, an independent writing center is distinguished (Fig. 2(a)), which consists of two specialized zones: the eye coordination field and the tracking and attention field (Fig. 1(a)). For full-fledged writing, the coordinated activity of the

listed fields is necessary with the participation of the extensive visual system located in the occipital hemispheres (Figs. 1(a) and (b)). For this reason, theories of agrammatism built on the idea of parallelism of syntactic disorders in the production and understanding of speech look primitive. They contradict significant discrepancies in the impairment of these functions in aphasia. These facts were noted about half a century ago, and to date, no approaches to solving this problem have been proposed [6].

People who can write and read are forced to operate with words to transfer their thoughts to writing. With this form of thinking, a person pronounces future texts constantly “to oneself,” which affects the structure of the facial muscles over time. Speaking to oneself occurs three times faster than oral speech but requires significant energy from the neocortex. The motor speech or Broca’s area takes the most active part in constructing the text “to oneself” (Fig. 1(a)). However, the control of the muscles of the pharynx and larynx is not enough to form speech internal prototypes of written speech. In addition to Broca’s area, the motor and sensory areas of the neocortex control the tongue, jaw apparatus, palate, facial muscles, lips, and neck. Their functional activity is complemented by the anterior edge of the temporal region which controls the processes of chewing, licking, smacking, and swallowing (Fig. 1(a)).

To pronounce words “to oneself”, hearing and remembering are required. There are cortical and subcortical centers for this purpose. For example, the auditory centers cooperate energetically with the brain. They are located on the inner surface of the insula and occupy a large space around Heschl’s gyrus (Fig. 2(b)). They concentrate on the tonotopic perception of sounds and their primary understanding. In this area, memory for words and phrases is stored, which is predominantly localized on the surface of the brain. Significant areas of the surface of the hemispheres are involved in the process of oral and written speech due to auxiliary functions. As the consequences of injuries and strokes of different natures and locations and pathological processes, clinicians increased the size of the neocortical surface structures of the hemispheres involved in writing (Fig. 2(b)). These areas are distinguished by the forms of speech, hearing, and writing disorders. Motor aphasia causes the disappearance of speech and partial impairment of writing due to pathological events in Broca’s area. Traumatization of the temporal region leads to sensory aphasia or Wernicke’s verbal deafness, and optical aphasia. Dejerine’s verbal blindness is formed due to neurological abnormalities in the cortex adjacent to the visual fields (Figs. 1(a) and (b)).

The largest and least structured area in a functional sense, is the general aphasia area. It contains auditory memory and trait, and integrates visual, auditory, and the sensorimotor perception of the external world (Fig. 2(a)). At first glance, the area of general aphasia looks unreasonably large, but this is an understatement of the problem since only auditory aphasia goes far beyond the designated boundaries [7]. The review and interpretation [8,9] of the results of 20 years of research conducted on positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have expanded the presented schemes according to the principle of minimalism [10]. The use of writing skills consumes about 40% of all energy expenditure of the brain only during the simplest dictation or mechanical rewriting of a finished text. If we allow minimal creative participation of associative areas, then they increase working energy expenditure by another 25–30%. It is impossible to experience such significant brain expenditure for a long time due to limitations in the metabolism of the central nervous system. All events occur in two hemispheres at once, which depletes the brain much faster [11]. Congenital cases of absence of Broca’s areas are found in the left frontal region which do not affect the speech functions of the patients. Amusia is observed with lesions of both the left and right hemispheres [12]. There is much evidence of the participation of the right hemisphere both in the formation of speech itself and in the restoration of functions in aphasia [13].

The cortical structure of the cerebral hemispheres is involved in the mechanisms of regulation of oral and written speech. The existence of subcortical centers for the regulation of speech functions has been confirmed, especially after the spread of computed tomography methods. In global aphasia (Fig. 2(a)). Damage to deep (subcortical) brain structures and excessive involvement in pathological processes of fields are weakly associated with both speech and hearing [14]. Studies of patients with vascular lesions of the nuclei of the neostriatum but without signs of damage to the cortex showed even more interesting results. Of the 37 patients, articulation disorders were found in three, while other functions were preserved, and in 13, signs of aphasia, dysarthria, apraxia, acalculia, and other disorders were revealed. However, the most interesting thing is writing impairment, while oral speech is preserved [15]. This phenomenon is partly explained by the destruction of axonal intercortical connections, but the persistence of written language disorders requires other explanations.

Based on meta-analysis of a large number of clinical and pathological cases, paradoxical results of brain research in the analysis of written and spoken speech are produced. The presence of a stable connection between the brain functions under consideration and many subcortical structures have been confirmed [16]. The subcortical centers of the brain are related to the formation of speech and writing including the entire complex of limbic centers (Fig. 1(b)). These observations are contradictory since they are expected to affect a person’s speech and writing abilities indirectly. However, the previously developed model of the duality of consciousness allows us to explain the reasons for the participation of the subcortical limbic complex in the formation of speech.

When making decisions, a person uses two competing neurobiological systems. When the brain is specialized according to biological type, it focuses on maximum efficiency in obtaining food for reproduction and dominance. Social restrictions and rules of behavior are a forced burden and are usually ignored. In this case, the energy expenditure of the brain is minimal, since the limbic system occupies less than 10% of the brain volume. With this behavioral strategy, neocortical knowledge of words, the ability to speak and especially write perform the functions of a data warehouse for servicing biological functions. Of course, the neocortex is involved in writing the text with its costs minimized. The meaning of a text is determined by the limbic system, which is extremely far from social or humanistic approaches. Ultimately, this induces a maximum reduction in brain energy expenditure, which is supported actively by endogenous cannabinoids. Illiteracy is biologically beneficial since figurative-event thinking does not mobilize such vast areas of the hemispheres for work.

A completely different situation arises with the use of a huge number of cortical fields involved in oral and written speech. In this case, the energy expenditure of the brain increases by seven to eight times, which is disadvantageous for the body. However, the advantages of voluntary thinking are used to create meaningful texts and even literary works of art. The development of cortical control over written speech is a criterion for separating biological motivations from socially determined ones. The duality of consciousness affects the form and methods of creating arbitrary text. Text analysis helps to separate the cortical and limbic thinking when writing a short text by assessing hidden or deliberately disguised forms of decision-making.

2. Materials and Methods

To research the individual features of written speech, a new method of pragmalinguistic analysis was used [17]. 300 volunteers of different ages, genders, and social statuses were invited to this study. An announcement about a linguistic experiment was distributed on Russian-language social networks. The volunteer was required to write an essay of more than 500 words on a free topic. The basic topic was: “The event that made the strongest impression on me.” They send their essays as well as their full name, age, gender, and photograph through e-mail. The participants were between 18 and 70 years of age, and Russian must be a native language for applicants. Only texts in Russian were considered. Over six months, 300 participants were accumulated. 60% of the participants were males aged 25–50 years old. 12 participants were under 25 years of age and males. The rest were women in the age of 25–50 years.

The texts of the participants were analyzed using several parameters showing consistent differences in written speech. One participant showed correlated indicators for most parameters. People had different uncorrelated indicators for parameters. The texts of the essays were compared in terms of the abundance of the author's syntagmas, occasionalisms, idioms, tropes, words with lexical components, as well as words beyond the scope of the frequency dictionary (within 6000 words), obscene vocabulary, euphemisms, argonisms, clericalisms, vulgarisms, truisms, cliches, speech errors. Not all participants were able to synthesize the author's syntagmas and occasionalisms. Participants who tended to use clericalism, vulgarism, and swearing in their written speech could not re-write the text.

Phraseologism was rare in the texts. However, several participants used them incorrectly or out of place, which indicated a saving of effort in memorizing a stable phrase and operating with it. Thus, they used familiarity with folk art. Vocabulary deserved special attention. Participants who wrote their texts according to the principle of sufficiency used neutral vocabulary, unambiguous words, or polysemous words. In the primary sense, they did not abuse figurative meanings, as well as words burdened with many components of lexical meaning. Efforts to save energy were observed for ready-made designs for all occasions including wording and thinking. Behind such phrases, thoughts were hidden or were lacking. For such purposes, universal clerical words and expressions in financial, popular science, propaganda literature, books on personal growth, sales, business ethics, and others were suitable. The main difference between such constructions was that they were not samples of the author's thinking, but impersonal, commonly used speech products. For example, «сейчас часто поднимается вопрос об актуальности» (“nowadays the question of relevance is often raised”), «пережиток прошлого» (“a relic of the past”), «пора переходить на электронные носители» (“it's time to switch to electronic media”), «работает мышечная и зрительная память, что способствует лучшему усвоению материала» (“muscle and visual memory works, which contributes to better assimilation of the material”), «данный факт я смело могу отнести к плюсам» (“I can safely attribute this fact as an advantage”).

Signs of voluntary thinking, on the contrary, were detected with the help of associatively meaningful words and combinations of words, in which the full meaning and emotional coloring were revealed not in the direct meaning but in an associative series. In the case of individual words, the effect was achieved due to their polysemy such as «уехать в сторону – сделать крюк» (“move to the side – make a detour”), multi-component meanings such as «собаки успокоились — псы обмякли» (“the dogs calmed down – the dogs went limp”), as well as stylistic affiliation such as «драка — мочилово» (“fight – soaking”). The combination of words allows the use of various speech techniques for the same purpose – transfer of meaning (the metonymy such as «замерзающая остановка» (“freezing stop”) or the metaphor such as «океян радиодеталей» (“an ocean of radio components”), etc.), context such as «Фонари уличного освещения стояли наизготове — еще пара часов и их должны были включить. Наизготове стояли и собаки» (“The

street lights were at the ready – a couple more hours and they had to be turned on. At the ready the dogs were standing too”) and apt quotation such as «Я сказала "Поехали!" и махнула рукой» (“I said “Let’s go!” and waved my hand”). These can be both stable phrases such as «глаза горят» (“eyes are burning”), and «заулыбалась во всю фотомордочку» (“she smiled all over her photo face”).

Each text was examined as a separate corpus, from which two categories of words and phrases were extracted. Syntagmas, occasionalisms, idioms, tropes, words with several lexical components, as well as words beyond the scope of the frequency dictionary (within 6000 words) comprised the first group. Obscene vocabulary, euphemisms, argonisms, clericalisms, vulgarisms, truisms, cliches, and speech errors belonged to the second group. Next, the ratio of the first and second groups in each case was calculated. A comparison of the results showed enormous individual variability in the use of these pragmalinguistic constructions while writing texts. About 10% of the participants, at the request of the experimenters, provided their old essays, written at least a year earlier, and a maximum of 10 years earlier. A comparison of the results of old and new essays by the same participants showed direct correlations in the first and second groups, as well as in the correlation of pragmalinguistic constructions within the groups.

The results obtained after analyzing the texts written by the participants were distributed hierarchically. The top positions were occupied by those essays in which the share of the first group was the largest. Texts with the largest share of the second group were positioned in lower positions. The shares of the first and second groups in the texts differed several times. The first group ranged from 0 to 50% of the total text. The second group ranged from 0 to 90% of the total text. The hierarchy was built according to the value of the share of the first group in the text. The average share of the first group in the comparison of all texts varied 10–15%. For the second group, the average value was not found. Accordingly, in the hierarchy of results, built according to the value of the ratio of the first group, the ratio decreased to 15%. The results in the hierarchy showed that the greater the share of the second group in the text, the lower the results descended in the hierarchy.

3. Results

The method of studying pragmalinguistic constructions in texts is used to assess the individual characteristics of associative and speech fields and subfields of the noncortex. The use of phrases from the first group – for example, syntagmas and occasionalisms – requires a neurological substrate, namely, associative and speech fields constantly in demand by the individual. They must have a large network of connections that allow them to manipulate the meanings of words deftly which are understood by the writer in all aspects. Most importantly, that allows them to synthesize new speech constructions in violation of existing language rules, while the constructions do not lose the meaning of the statement, but vice versa clarifying it [18]. On the contrary, the second group simplified the use of speech, that is, universal pragmalinguistic constructions were generalized rather than clarified for the meaning of an utterance and sometimes were absent. Obscene words and euphemisms were observed mostly, as well as clericalism and cliches. This is indicated by the possibility of the inlay into almost every part of the narrative without significant consequences for the content of the message. At the same time, the burden of deciphering the message mainly falls on the reader, who is forced to independently complete the author’s speech. This principle of “speaking and listening” was described in 1940 by a student of Ferdinand de Saussure, one of the publishers of his “Course of General Linguistics” — Albert Sasset. Later, the representative of French structuralism, Andre Martinet, began studying and describing the principle of “speaking and listening”.

The correlation of pragmalinguistic constructions from the first and second groups demonstrated the energy balance of the brain between the limbic system and the neocortex. The first one saved efforts since it was biologically beneficial. Using the capabilities of the neocortex was energy-consuming for the body due to the long evolution of primates in conditions of food shortage. The writer of the text used pragmalinguistic constructions of the second group excessively to save effort due to the impossibility of shifting the balance in favor of the neocortex and unclaimed or quantitatively modest associative speech substrate. The second option indicated the proportion of pragmalinguistic constructions of the first group. The choice of the length of an essay on an arbitrary topic of at least 500 words was not accidental. The measure was empirical. On the one hand, in a text of such length, the writer faced non-trivial linguistic tasks that forced the writer to choose either to use associative and speech centers to find an individual solution or to use ready-made universal constructions sacrificing the accuracy of the narrative. On the other hand, the length of the text was too long for regular access to associative and speech centers for the writer. This was beneficial only if associative and speech centers were constantly in demand, which means they had a large number of specialized connections and many tools for solving non-trivial language problems. From a biological point of view, this method helped to achieve better communication and increased dominance. The difference between in-demand and unclaimed associative and speech centers was found in the first group due to the large number of connections. A successful solution could be found more easily and faster than in the second group. Therefore, less effort, that is, energy was required.

As a result, a writer with large and in-demand associative and speech centers had the choice of either saving time and effort by abandoning the search for solutions to non-trivial language problems or demonstrating to the reader the capabilities and increasing dominance. At the same time, better practical results were obtained, that is, more accurately expressing the writer’s thoughts. A

writer with small or unclaimed associative and speech centers had a different choice. Either saving time and effort or spending them excessively with an unguaranteed result. An experiment was conducted to confirm this.

The writer of the essay with a large share of pragmalinguistic constructions of the second group was researched specifically in this study. He was 35 years old. He was given the task of writing a new essay, also in an unlimited amount of time. However, now he had to increase the proportion of pragmalinguistic constructions of the first group in the text. Unfortunately, he was unable to do this. As a result, the share of the second group increased due to a large number of speech errors, that is, the size of associative and speech fields and the volume of connections did not allow him to solve non-trivial language problems successfully, which led to imitation, that is, inept imitation of the narration of writers known to them and rude speech mistakes.

Comparison of the identified trends in the writers' texts made it possible to arrange the research results into a hierarchy. In this case, the participants were divided into two large clusters: 171 and 87 people. The texts in each of them were comparable in terms of the quantity and quality of various speech structures. The criteria were found empirically. The first cluster included results with the ratio of the first group in the text more than 15%. Moreover, in such texts, the ratio of the second group was less than 30%. The second cluster included results where the ratio of the first group in the text was less than 15%. In such texts, the ratio of the second group was higher than 30%. Few texts whose results were at the top and bottom of the hierarchy were used for individual studies.

The first group included writers whose diligence in searching for linguistic solutions was beneficial from a biological point of view. The goal was achieved with minimal means. The idea was formulated using common techniques and general words, as mentioned above, stylistically uncolored, and most importantly, mistakes in the use of which were practically excluded. Such vocabulary was used in official documents and well known translators such as Clerk [19,20]. A primitive dictionary of clerical words and expressions such as «эффективный способ» (“effective method”), «реализация» (“implementation”), «в сложившейся ситуации» (“in the current situation”), «специализация» (“specialization”), «на протяжении определённого количества времени» (“for a certain amount of time”), «в обсуждаемых вопросах» (“in the issues under discussion”), «расширился функционал» (“functionality has expanded”), «мотивация» (“motivation”), «данный факт» (“this fact”) and others are universal for almost any communicative situation.

The essence of the message was stated, and obscene vocabulary competed with bureaucratic words for use. However, the participants in the experiment were reluctant to resort to it in their texts because the dominance of the writers diminished. The second group with writings with apt words and phrases, and simultaneously clarified the additional details of the message. The writer's attitude to the events presented with the features of individuality. For this multi-layered written language, the energy expenditure of the brain was important to keep more sophisticated vocabulary in memory and, most importantly, regularly feed the associative and speech centers for intended purposes to solve non-trivial language problems. The experiment result demonstrated a clear boundary between those with a better result and their energy saved. That is, there were two groups of writers: who expressed their thoughts as accurately as possible and who simplified their speech. Thus, written speech can serve as an indicator of the energy balance of the brain between the limbic motivation to save energy and the cortical motivation to achieve a rational goal. Due to the huge area involved in oral and written presentation, the results of speech creativity can be used to assess the demand for the required zones of the neocortex. Their degradation cannot but affect their behavior.

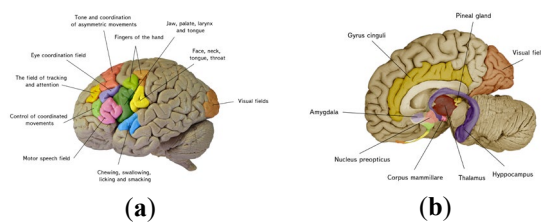


Fig. 1. The human brain with centers applied to its surface that are directly involved in writing the text. Writer Sergei Saveliev. (a) The lateral surface of the hemisphere with the motor and visual centers of the fields that control the process of writing the text; (b) The medial surface of the hemisphere with limbic and visual centers that determine the biological motivations for writing.

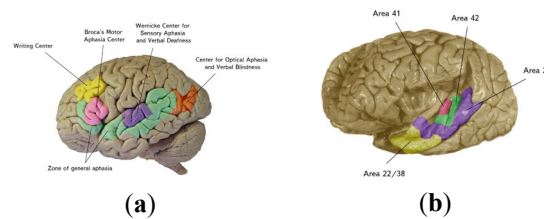


Fig. 2. The human brain with cortical centers applied to its surface, damage to which causes various forms of aphasia. Writer Sergei Saveliev. (a) Main areas of aphasia formation and localization of the writing center; (b) The inner surface of the insula and the gyrus of Heschl with the main human auditory fields.

4. Conclusion

The results of this study showed that to write speech, the human brain uses cortical fields of various functional specializations. To create and develop oral and written speech skills, the auditory fields of the neocortex are used in Heschl's gyrus. This functional complex includes four fields that determine the ability to perceive and accumulate auditory linguistic experience. When memorizing and pronouncing words without external generation of sounds (to oneself), more parts are involved, providing the motor basis of articulation. First of all, these are the cortical tongue control centers, pharynx, larynx, masticatory areas, and motor speech field (Broca). In complex logical reasoning, people think in words by speaking, which is about three times faster than speaking. This allows for thinking faster than speaking. Thus, even oral speech requires the involvement of about a quarter of all resources of the neocortex of the human brain in the process of meaningful word generation. When writing a speech, more brain centers are involved in the physical recording of meaningful speech. Simple algorithms for generating words were created based on personal experience and stored in memory. A long sequence of interconnected words is needed to be coordinated. Operative reflective memory used in oral speech, is no longer enough to operate. It is necessary to build a hierarchical structure for a meaningful presentation of the expressed thoughts. First, a general idea of a written text is created, and then it is divided into meaningful independent blocks. Each block is then formatted with related linguistic constructs and filled with appropriate words. In such a complex problem, all available associative areas of the neocortex are involved. They are localized in the frontal and inferior parietal areas, which does not require special explanation. For this study, even when planning a written speech, the higher associative centers that arose in human evolution were observed.

Preparation for the implementation of written speech is not limited to the involvement of the centers of hearing, memory, and associative areas of the brain. When writing a text, motor and visual centers are involved in synthetic activity. Since the text is presented on paper or a computer monitor, the occipital visual fields play a huge role. In addition to them, control over the movement of fingers and hands, centers for determining the coordination of asymmetric movements, fields of attention, and coordination of eye movements play an important role. In other words, the most evolutionary control centers for the movement of hands and eyes form the physical basis for transferring thoughts onto paper or into a computer. Consequently, written speech is the main sign of rational hominization to assess a person's ability to think voluntarily and meaningfully. To individualize linguistic assessments of written speech, individual variability needs to be considered [1]. The main variability of the brain can be increasing by 300–500%, which makes the design of each person's brain unique in its potential capabilities. On the ability to spend one or another part of the energy of the brain, self-realization in synthetic texts affects markedly. For this reason, each text reflects the characteristics of the individual brain structure and potential abilities for the energy sacrifices of a non-biological nature. Ultimately, this makes it possible to assess the abilities of voluntary thinking and the creative potential of a person based on the linguistic manifestations of written speech.

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