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RESEARCH ARTICLE

Short- and Long-Term Changes in the Neurophysiological Status of Pilots Due to Radiation Exposure Caused by Geomagnetic Storms

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ABSTRACT
Pilots who have completed successfully all the tests of cognitive and personality psychology have a strong commitment to their movements, and they influence their neural stimulation, such as the ability to acknowledge the right steps to follow in their tasks or dangerous situations. One of the branches of *Aviation Psychology* is dealing with the physical and mental effects of flight on aircrew personnel and passengers. Astronomical events, such as geomagnetic storms (GSs) that have a disruptive effect on Earth's magnetosphere in certain periods, will cause negative effects on aircrew personnel and passengers. This article describes the expected damage to the different areas of the brain and nervous system in short- and long-term periods caused by the effects of GSs, based on the results of previous studies on GSs and neurophysiological studies. This is a very important topic for neurophysiological studies of pilots when we consider that aircraft accidents that may be geomagnetic in origin accounted for 26.36% of the total accidents which coincide with the days of GSs. Decision-making and judgment problems, abnormal attitudes such as anger, fearlessness, temerity, self-confidence, etc., decreasing problem-solving abilities, organization capabilities, and instantaneous decisions are the short-term changes while developing cancers of the brain, testis, bladder, breast, colon, melanoma, and Hodgkin's type, in addition to Alzheimer's and dementia diseases, hypoglycaemia, stroke, epileptic seizures, insomnia, stomach bleeding, appendicitis, hernia, asthma, and severe spinal pains can be lead in the long-term changes. We mentioned the psychological and medical application method of EEG in our article since it is the best technique that allows us to see the effects of these storms in the laboratory environment. This is because, the aircrew personnel and passengers flying at high latitudes will experience the effect of the GSs directly, whereas the response of the pilot, flight crew, and passengers flying in the middle latitudes, to these effects, can be measured only with tests in the laboratory environment. This paper has also special importance for the aviation literature because a theoretical recommendation regarding the possible laboratory environment for EEG measurements and application procedures necessary to investigate these effects is also presented.

Keywords: Aviation psychology, Cognitive psychology, Geomagnetic storms, Neurophysiology, Nervous system.

Nomenclature

ACI	: Air Crash Investigation
Ca	: Calcium
CH	: Coronal Hole
Cl	: Chlorine
CME	: Coronal Mass Ejection
CNS	: Central Nervous System
CR	: Cosmic Radiation
CVS	: Cardiovascular System
Dst	: Disturbance Storm Time
ECG	: Electrocardiogram
EEG	: Electroencephalogram
GA	: Geomagnetic Activity
GS	: Geomagnetic Storm
ICAO	: International Civil Aviation Organization
K	: Potassium
MF	: Magnetic Field
Na	: Sodium
NRC	: Aviation Psychology National Research Council
NTSB	: National Transportation Safety Board
SAC	: Solar Activity Cycle
SC	: Solar Cycle
SW	: Solar Wind
WEAAP	: West Europe Agency of Aviation Psychologists

1. Introduction

Some organic processes operate based on human behaviour. These organic processes that occur in the brain pass to the muscles and are then reflected as behaviours exhibited[1]. Environmental changes such as air pressure, temperature, or humidity affect neurobiochemical (the study of the biochemical basis of nerve cells which is influenced by the environment, and how small molecule neuromodulators such as proteins, peptides, and lipids shape the nervous system[2]) events in the body (Figure 1(a)), and the behaviours that emerge because of these neurobiochemical changes can be examined neurophysiologically[1]. Neurophysiology is the branch of physiology that deals with the functional properties of neurons, glia, and networks. The functions of the nervous system have been dominated by electrophysiology and the electrical recording of neuronal events ranging from the molar (the EEG) to the cellular (intracellular recording of the properties of single neurons)[3]. Nervous excitations process the information transmitted to it by nerve cells called 'neurons', through an electrical and chemical network, and transfer it to the brain, and the brain applies the appropriate motor reaction in response to this information. In general, this reaction ranges from 0.1 to 0.2 seconds. However, at three times the speed of sound, it takes 1.5-2 seconds for a jet pilot to comprehend such a situation[4]. For this reason, neurophysiological examinations of the changes in the neurophysiological status of pilots, whether civil or military aviation, as a result of the effects caused by various environmental factors and within very short time intervals, should be done much more comprehensively and by adding different parameters.

A person must have developed cognitive abilities, have a strong determination in his/her movements, and have successfully passed all cognitive and personality psychology tests that affect his nerve impulses, such as knowing the right steps to follow in his duty or dangerous situations to become a pilot[5]. The cognitive abilities of pilots play an important role in the success of combining speed and precision in information processing. The second important condition is that the pilot has personality traits such as courage, self-discipline, anger control, self-confidence, and the ability to cope with situations involving great risk[5].

"*Cognitive psychology is a branch of science that studies perception, memory, and information processing periods, and it investigates the relationship between the type and structure of cognitive processes in the organism and the type and characteristics of observable behaviours. Personality psychology, on the other hand, deals with the behaviour, thought, and emotional patterns of individuals*"[1].

'*Aviation Psychology*' refers to all information relating to general aviation, such as performances and support of cabin crew, passengers, if any, air traffic control system administrators and control team, airline personnel, and all other responsible persons, and those responsible for all design and maintenance of the aircraft, includes the application of people based on their behavioural skills and limits in the face of all these this information above[6]. In other words, aviation psychology is a science that has a key role in a wide range from trying to understand the flying person, conducting tests and interviews to find the right people in the selection of the flight candidate, finding solutions to the risky thoughts and behaviours of the flight candidate and their psychiatric disorders[7]. The aviation that developed in the early twentieth century despite the attempts to fly centuries ago, the skills of pilots, and the new environmental effects on pilots led to the emergence of the first aviation psychologists.

In early times, these people consist of individuals who received training in the fields of medicine, psychology, and physiology and engaged in these occupations commonly addressed psychophysical applications such as the acquisition of flying skills, unique grasping needs, and the study of physical stresses[6]. During World War I, particular attention was paid to the development of the capabilities of the first aircrafts and the selection and training of people who would use them. However, the concept of aviation psychology was first introduced in Germany in 1915 during this period. In the following years, aviation psychology focused on the aircraft itself (especially the effects of altitude, G-force, noise, temperature, and other environmental pressures on the pilot)[6]. Psychological tests, on the other hand, started in June 1917, with research conducted at the Massachusetts Institute of Technology (MIT) with the participation of Air Force students in the United States. As a result of these tests, a relationship was found between flight training performances, emotional stability, slope perception, and mental agility; however, the emotional stability used here is different from the emotional stability we use today[6].

During the war years of 1920 and beyond, aviation psychology was reviewed in Italy, France, England, and the United States, and in 1939 the NRC was established in the United States. In 1947, the American Air Force prepared a 19-volume series on aviation psychology, also called the '*Blue Book*', and in 1949, a laboratory for aviation psychology was opened in the state of Ohio, United States while the WEAAP was established in Europe in 1956. In 1971, a more advanced aeronautics research laboratory was opened at the University of Illinois, and all this research was published in a book in 1980[6].

After the 1980s, especially the effects of meteorological events on aviation psychology began to be studied. Continuous improvements are made in the aviation rules of Annex 1-19, published by the ICAO at regular meetings. Annex 3 only contains the research and results of the effects of meteorological effects such as rain, fog, snow, low cloud height, etc. on aviation activities and aviation psychology. However, during this time the effects of GSs had not yet been more effectively addressed. The effects of GSs, which have been known for nearly 200 years on civil and military aviation have been revealed in a document published by the United Kingdom Aviation Industry in 2013[8,9]. After this time, progress has been made in the research on the effects of GSs on aviation psychology.

Human brain activity and functions are affected significantly by the GSs that are seen in different intensities. The human brain is an organ in the skull in the form of left and right hemispheres, which is covered by the cerebral cortex and is responsible for different functions[10] (Figure 2). The right hemisphere is the part that is strong in visual perception, receives and processes information not piecemeal but totally, allows attention to be shifted from one point to another, and can evaluate more than one piece of information simultaneously while the left hemisphere is the part that is important for the operation of verbal information, processing information piecemeal and sequentially, focusing and maintaining attention[10]. Both hemispheres of the brain have complementary functions. Therefore, the two hemispheres of the brain connect through a neural link consisting of approximately 250 *million* nerve fibers, and both hemispheres contribute to learning[10].

There are important differences between the way people perceive, think, and learn. The reason for this is that each person's brain structure is created in a different perception and learning system. The functioning of the human brain, where there are two types of cells, '*nerve (neuron) cells*', and '*glial (glue) cells*', takes place through communication between cells. Neurons, which are the main elements of the nervous system and brain functions consist of three parts: '*cell body*, *dendrite*, and *axon*'[10].

Dendrites collect the incoming inputs to the cell, and it is decided whether an output pulse can be produced by combining them in the cell body. If a job is to be done, the output pulse produced is carried by the axons and transmitted to the connections with other neurons. Connections between neurons occur in the cell body or at transitions in dendrites called '*synapses*'[11-13] (Figures 1(b)-(d)). Learning and storing information in the brain occurs with electrical and chemical signals between nerve cells.

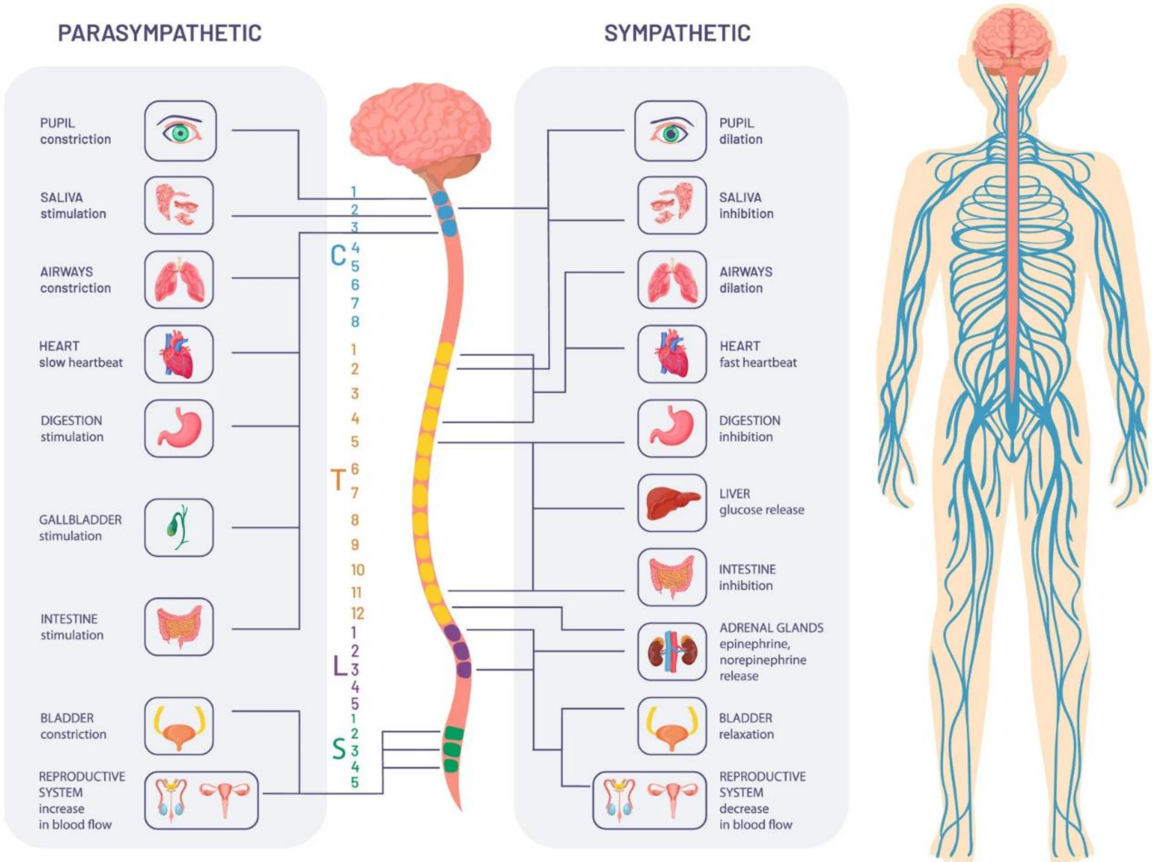

Figure 1(a): Autonomic Nervous System of Human. Here, C, T, L, and S correspond to Cervical Nerves, Thoracic Nerves, Lumbar Nerves, and Sacral Nerves. There are 8 Cervical, 12 Thoracic, 5 Lumbar, and 5 Sacral Nerves that form the autonomic nervous system and they are named spinal nerves[14].

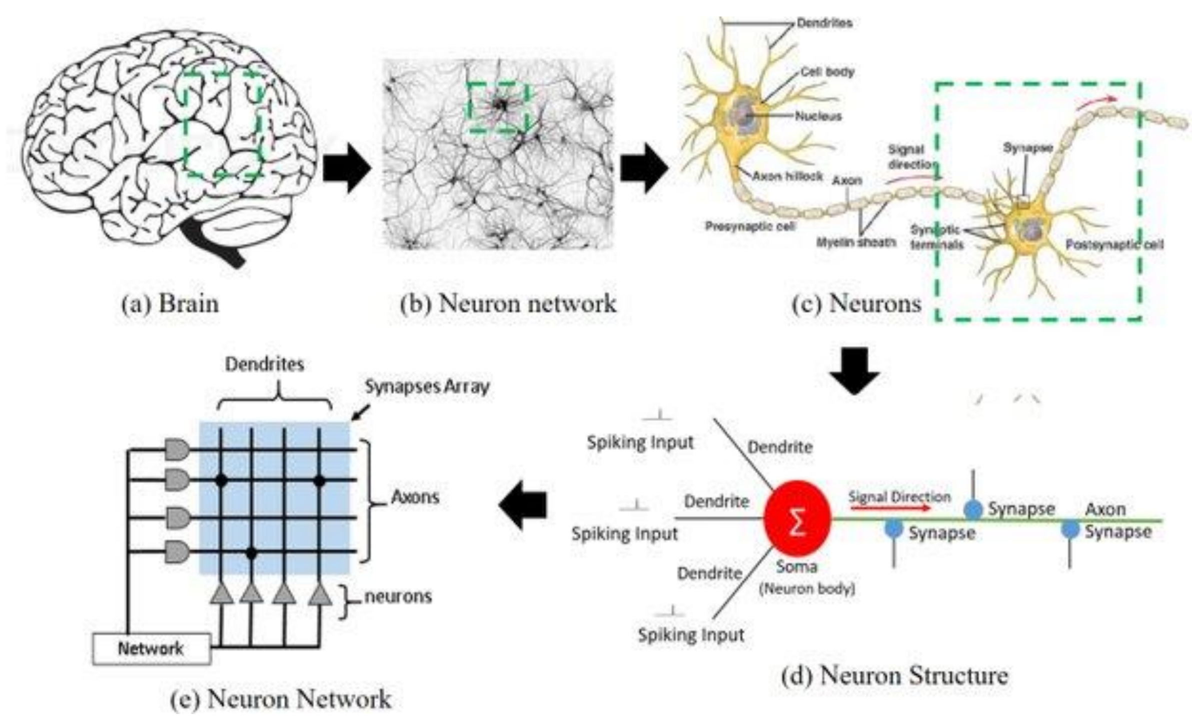

Figure 1(b): The General Structure of Neuron Network[11].

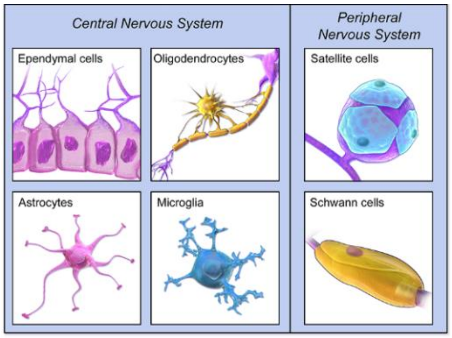

Figure 1(c): Types of Neuroglia[12]

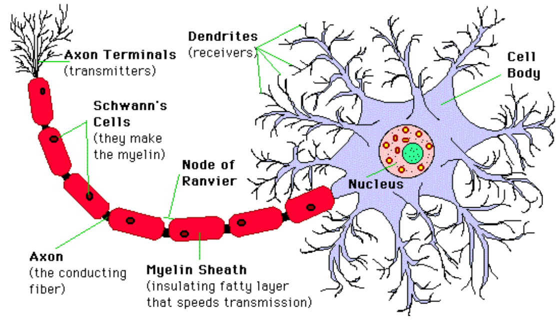

Figure 1(d): The Structure of Neuron [13].

Neurons produce electrical signals by changing the voltage on the cell wall using ions such as Na, K, Ca, and Cl that are distributed inside and outside the cell. A cell transfers electrical energy to another cell through these chemical ions. While some ions cause electric and magnetic polarization, some get rid of polarization and allow ions to pass into the cell body by opening the cell membrane. Signals determine the activity, '*impulse*', of the cell. A neuron affects other cells by the amount of impulse it has. Some cells affect the impulses of others positively, and some cells negatively. The brain and nervous system and the formation of cognitive behaviours are the basis of brain-based learning. Brain-based learning is a learning approach based on the function and structure of the human brain and connects with neuroscience, neurolinguistics, and cognitive psychology[10]. As described above, the brain has different spatial and anatomical functions. Our aim in this article is to investigate what kind of changes of GSs will cause in these brain functions.

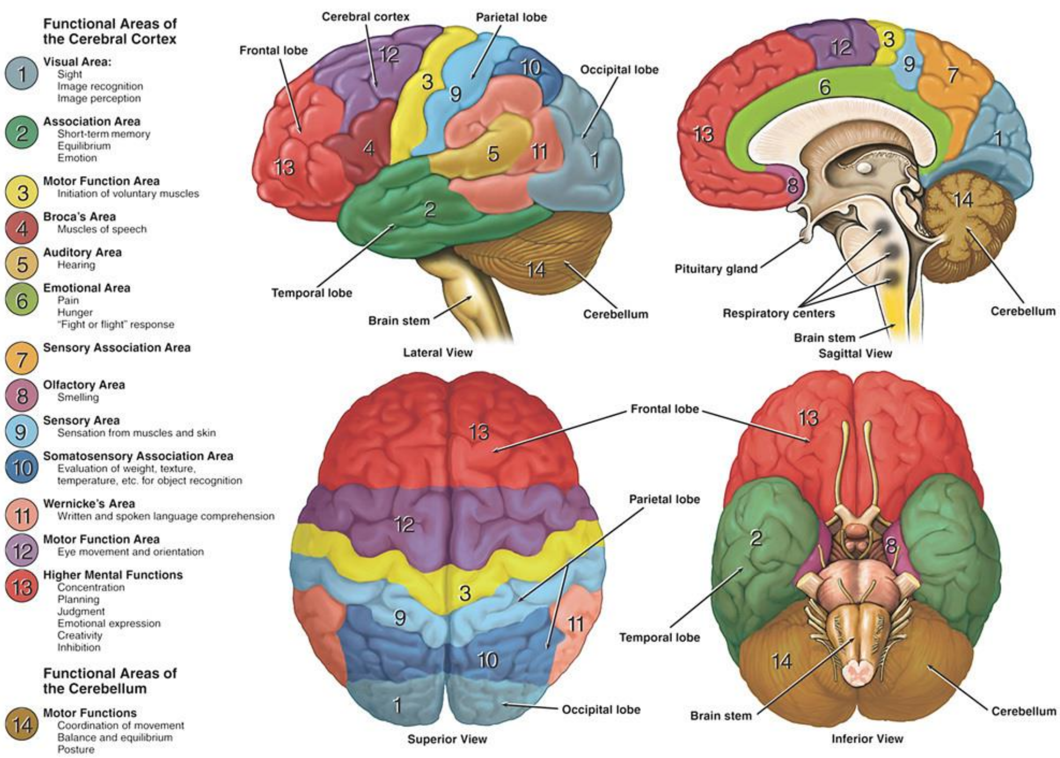

Figure 2: Functional Areas of the Cerebral Cortex including Motor Cortex (Areas 3 and 12) and Temporal Cortex (Area 2), and the Cerebellum[15].

Babayev and Allahverdiyeva[16] stated in their article that EEG examination results are the most objective method that reflects the functional state of the human brain. During the periods of strong GSs, disharmony, weakness, and the presence of headaches in different areas were noted for the majority of volunteers. They showed that the complexity of unidentified shifts on the EEG (Figures

3(a) and 3(b)) reflects dysregulated functional activity in the cortex of the hemispheres of the human brain affected by GSs, possibly in association with the loss of function seen in integrative systems below the cerebral cortex, with increased synchrony instability. In the same article, it was stated that the threshold value of the mechanism of the human brain responsible for contractions decreased. They concluded that there is a strong effect in very severe storms for a certain period, but then, as in the working principle of neurons, after a certain point, there is no warning occurs, and the system will be blocked while weak and moderate GSs have a stimulating effect generally. Results of EEG investigations were used as the most objective method reflecting the functional state of the human brain. In Figure 3(a), the sketch of how to record an EEG signal is given. Electrodes are attached to an EEG cap which is multi-channels (16 channels) to catch the signals of gamma, beta, alpha, theta, and delta from the various areas of the brain and different frequencies of these signals are merged with the amplifier to draw each measured potential on the screen. In Figure 3(b), the wavelength ranges of these different frequencies are given, and digital recording is made for physiological characteristics[17].

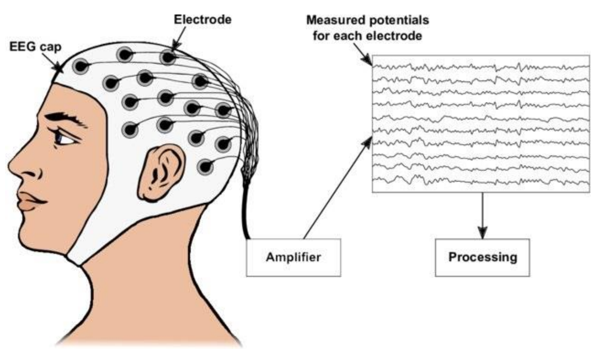

Figure 3(a): Sketch of how to record an Electroencephalogram (EEG) signal[18].

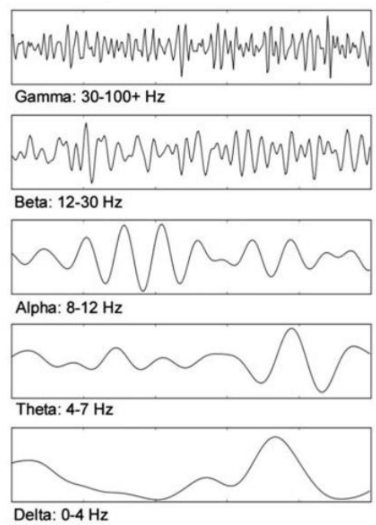

Figure 3(b): The five most common EEG bands and their frequency ranges[19].

The experiments are carried out in the standard system from the frontal, central, parietal, occipital, and temporal areas of both hemispheres of the human brain[16]. Raw EEG frequency bands include '*Gamma* (γ), higher than 30 Hz' reflects the mechanism of consciousness where the amplitudes are less than 2 μV. It is seen in REM sleep, learning and extreme happiness moments; '*Beta* (β), between 12-30 Hz' have amplitudes between 1-5 μV. The symmetrical distribution is usually seen on both sides and is prominent from the front. Waves are active when resisting or suppressing motion or solving math; '*Theta* (θ), between 4-7 Hz' and their amplitude is between 5-100 μV. The lowest waves of θ represent the line of being awake or asleep, thus in adults, high levels of θ are considered abnormal; '*Delta* (δ), less than 4 Hz' and their amplitudes are 20-40 μV. The amplitude tends to be the highest and in the slowest modes. It is normally seen in adults in deep sleep and infants; '*Alpha* (α), between 7-12 Hz' and their amplitudes vary between 2-10 μV. The interval seen in the posterior regions of the head on both sides is higher in amplitude on the dominant side. It is seen at rest, meditation, and before falling asleep, waves as given in Figure 3(b). Their ranges overlap along the frequency spectrum by 0.5 Hz or more[17,20].

The most important causes of organic problems in aviation such as headaches of unknown origin, irregularity in movement functions, and balance disorder, which are the main subjects of aviation medicine, are '*hypoxia*' (ascending to high altitudes, hypoventilation or the fact that the air inlet and outlet required to maintain the normal gas level of the blood is below normal, decreasing of oxygen transmission from the atmosphere to the blood through the lungs due to reasons such as lung diseases), '*acceleration forces*' (change in the velocity and/or direction of the object due to gravity), '*spatial disorientation* or *volatile vertigo*' (the state of imbalance caused by the balance systems of body, that is, the false stimulus to the eyes, inner ears, neck and spinal cord which send notifications to the cerebellum or the wrong perception of correct stimuli), '*fatigue*', '*shift-lag*' (the state of strain caused by the inability of the body's internal rhythm to adapt to this new order such as the changing of geographical regions, intense working times, partial or complete displacement of the sleeping period), '*jet-lag*' (a series of mental and physical performance impairments caused by long-range and high-speed intercontinental journeys crossing longitudes, and the mismatch between the internal-biological clock and the geographic time of the destination), '*thermal stress*' (an uncomfortable condition resulting from an increase in temperature), and issues such as '*dehydration*' or '*water loss*'. This will be much more effective for pilots who are more exposed to the effects of GSs.

The main aim of this article is to investigate what kind of changes of GSs will cause in different functional areas of the cerebral cortex, motor cortex, and temporal cortex with the cerebellum in which the research of a process that is difficult to study and requires a very long time to collect data, and therefore requires a large number of volunteers and a good laboratory. The studies of Babayev and Allahverdiyeva[16] that reflect the functional state of the human brain are used while investigating these changes. The scope of this paper is to explain the structure of GSs and referring to which regions of the human brain are affected by these storms, and their possible damages in short- and long-time changes. As seen from the results, the greatest impact of the storms is expected to be directly on the nervous system through the cortex, especially in the right cortex which is dominant in cognitive functions that require visual-locational-spatial material processing.

In our study, we investigated the psychological and medical application method of EEG since it is the best technique that allows us to see the effects of GSs in the laboratory environment. This is because, the aircrew personnel and passengers flying at high latitudes will experience the effect of the GSs directly, whereas the response of the pilot, flight crew, and passengers flying in the middle latitudes, to these effects, can be measured only with tests in the laboratory environment. However, a research laboratory has not yet been established for the possible effects of GSs on the volunteers and has not been investigated yet in many countries which are members of ICAO. So, laboratory studies should accelerate as soon as possible for the middle/low latitude geographic regions. This paper has also special importance for the aviation literature because a theoretical recommendation regarding the possible laboratory environment for EEG measurements and application procedures necessary to investigate these effects is also presented.

Our theoretical recommendation is important because such a theoretical study is presented for the first time in aviation psychology literature. Although not many studies have been done, the current investigations are generally ground-based studies on volunteers after the occurrence of GSs. However, in our theoretical recommendation, we propose to compare the tests of cognitive and personality psychology of the volunteers before the GS and after the GS.

In our paper, we will discuss the results obtained from the studies of Babayev and Allahverdiyeva[16] on pilots. Based on these discussions, the astronomy, and near-space physics information on the subject needed for their studies that psychologists, physicians, biologists, and other researchers who want to research this subject will also be presented within the scope of our article. In Section 2, the effects of changes in GA on the functional state of the different areas of the human brain are given, and in Section 3, short- and long-term changes in the neurophysiological status of pilots depending on the GSs are asserted. The effects of GSs on human brain functions and neurophysiological status of pilots are discussed in Section 4 while conclusions are given in Section 5.

2. Effects of Changes in Geomagnetic Activity on the Functional State of the Human Brain

A GS is an astronomical event that disrupts the order of the Earth's magnetosphere (It is a comet-like structure that surrounds the Earth and other planets in a way that traps charged particles and changes their direction (Figure 4(a) and (b)). The SW and the MFs of the planets determine the shape of the magnetosphere[21,22] and its physical unit is expressed as nanoTesla [nT]. Solar-induced effects that cause a GS are CMEs (explosions that cause a sudden increase in the SW), CHs (variable solar events that can last for months or even years, seen as large black holes during X-ray observations of the Sun), solar flares, and the one that transmits these effects towards the Earth is the SWs advancing through shock waves[23-27]. The differences between CMEs and CHs are shown in Figure 4(b). The MFs generated during GSs are carried by the plasma of the SW. SWs continue to be effective even after 24-36 hours from the moment of the event they interact with the Earth's magnetosphere.

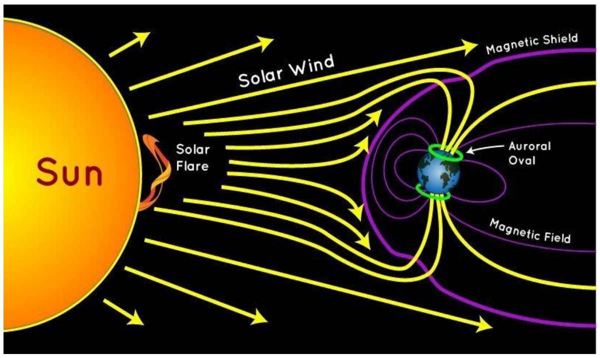

Figure 4(a): The Sketch of Geomagnetic Storm and Interaction with Earth[29].

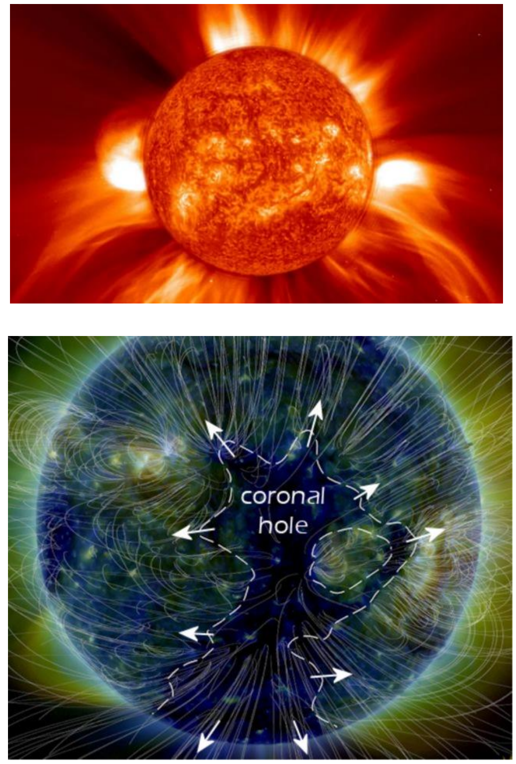

Figure 4(b): Images of Coronal Mass Ejections[30](above) and Coronal Holes[31] (below).

Depending on the effective structure of the CHs in the decreasing phases, the number of aircraft accidents increases in the decreasing phases of SACs. In addition to this, the lower number of accidents was seen in the solstices (e.g., June and December) while the highest number of accidents occurred in the equinoxes in March and September, and mostly at the beginning of October[28]. The galactic CR flux enters the Earth's atmosphere at much larger scales in the minimum phase of SA rather than the solar maximum. Thus, the number of CHs is higher at lower latitudes while they are much smaller and short-lived near solar maximum. In contrast to this, the higher flux in the minimum phase is the CHs inclined to be fewer at high latitudes, but they are larger and longer-lived near the solar minimum[28].

The interaction time and the intensity of the GS with the Earth's magnetosphere are measured by a parameter Dst and its unit is [nT][32, 33,34].

$$Dst* = Dst - b \times PSW0.5 + c \qquad (1)$$

Here, the Dst* index is defined as the pressure-corrected Dst index corresponding to the correction of magnetopause current effects (plasma currents in the magnetopause that mark the boundary of the Earth's MF between the solar system); the Dst index includes components of geomagnetic field changes in the magnetopause current and tail currents since the magnetosphere is a comet-like structure; *b* and c values are constants obtained as a result of the analysis and PSW is the SW dynamic pressure (dynamic pressure is the pressure in the direction of the fluid movement) and is measured in [nPa] (1 nanoPascal = 10-15 Newton/mm^2)[35]. Generally used *b* and c values are b = 7.26 [nT(nPa)$^{-1/2}$] and c = 11 [nT], respectively[32].

Another parameter that measures the intensity of GSs is called the K-index (or planetary K_p-index). This parameter takes observation data of GS every 3 hours to capture the intensity changes from the calm (K_p=0) to the most disturbing (K_p=9) intensity values[36]. With the development of satellite technology, the structure of the Earth's magnetosphere has begun to be investigated in more detail. The most important result obtained because of this research is that high radiation sources such as mass, momentum, and energy emanating from the sun and transporting to the Earth via SWs will be seen more frequently in the magnetosphere-ionosphere-thermosphere system, which occurs at high latitudes. However, if the intensity of this CR (i.e., the stronger GS) is very large, it has also been measured that it possibly goes down to the middle latitudes[28].

The increase in GA is due to the decrease in the drift velocity depending on the decrease in the horizontal component of the Earth's MF and the decrease in the electron density in the ionosphere with the increase of magnetic latitudes. However, the 11-year SAC and the 22-year magnetic cycle of the Sun will also cause significant changes in the intensity of GSs. Therefore, an equation has been created for the measurements of the storms and magnetospheric storms occurring in the ionosphere-inner magnetosphere according to the SAC. The general variation of increasing storm numbers is as follows[37]:

$$Y = a + b\Phi \quad (2)$$

Here, the Y value is a constant belonging to the indices W_p (it is an index due to wave and planetary influences, observable with ground telescopes for low latitudes), Dst, and Ap (giving the daily average value of GA) and varies according to the coefficients *a* and *b*; coefficients *a* and *b* are constants for the number of storms according to the SAC; Φ gives the phase of the SC given as

$$\Phi = (T - m) \,/\, (M - m) \quad (3)$$

Here, *T* is the month of the storm, *m* is the month of the solar minimum, and M is the month of the solar maximum. The Φ value mentioned since 1999 is "0.1 Φ"[37].

The other important parameter, the A_p index corresponds to an average magnitude and daily measure of magnetic activity, while the *aa* index measures GSs at the Earth's surface and is obtained from the range of variation in 3-hour intervals of K-values. The *am* index, another important parameter that measures the GSs is an average of eight 3-hour indices calculated using K-values from the observatories located at subauroral latitudes[28], and all these parameters identify with [nT].

The increased amount of radiation due to GSs will have a significant negative impact on the pilot and other flight crew. In particular, the effects of CR will be felt much more intensely during flights at high latitudes and polar regions. Although it is known from the statistics of accident reports made for more than 20 years that 70-80% of aircraft accidents are caused by human factors while accidents caused by meteorological events constitute 20-30% of this number[38]. Göker et al.[39] found that 58% of accidents are technical reasons while 27% of accidents correspond to pilotage reasons for 115 years of ACI data. It is also seen that 15% of these accidents are still unknown. In the paper of Aksen et al.[28], how GSs affect the air crashes is shown with the statistical analysis of 115 years of ACI in detail. The NTSB, established in the United States of America, reported air and visibility-related aircraft accidents in 1968, 1974, and 1989, but these reports and the aircraft accident report due to weather conditions in the following years include only rain, fog, low-cloud height, and snow[38]. At that time, the damaging effects of GSs on flight instruments were not yet known. GSs are defined as fields of physically ionized radiation. Atmospheric ionization is caused by two sources: (1) background galactic cosmic rays, which are constantly present outside the solar system and mostly affect astronauts; (2) charged energetic particles coming towards the Earth from eruptions on the surface of the sun, with a time interval ranging from a few hours to a few days which affects aircraft moving around the Earth[40]. In the last SC (SC 23), the very severe GS called Halloween, seen between October and November 2003, is the best example of the second source[40].

In very severe GSs, fatigue, malaise, and non-regional headaches that causes are unknown are the most prominent disorders, causing irregularity in the movement functions of the cerebral cortex, and dysfunction in the integrative subcortical systems which is associated with increased balance disorder[16]. In this article, it is found that the right cortex has been affected in sudden and short-term periods at certain time intervals on days of strong GA changes while the inner region and inner shape of the brain are weakly affected on geomagnetically calm days, but these experiments were done only for volunteers on the ground. This is a very important hypothesis; although the effects of the GSs on the pilots inside the aircraft, and the level of the negative impact of the GS which has such a stronger effect rather than on the ground.

The greatest impact of these storms is expected to be directly on the nervous system through the cortex. As a result of a direct effect on the nervous system through the cortex, aggression in behaviours, different seizure states, nervous system-related mental disorders, and suicide attempts are seen very common, in addition to these neuropsychological diseases are also increasing[1]. On the other hand, Babayev and Allahverdiyeva[16] stated that blood viscosities increase markedly during storm times, and in some cases, there is an increase in the form of double peaks, and red blood cells become sticky and blood flow slows down. So, how does this cerebral cortex and nervous system interact?

Cell bodies, also called efferent groups, convert physical energy in the eye, ear, skin, and other sensory organs into neural energy, transmit this energy to the brain, and enable us to perceive the outside world. From this transmitted energy, the brain and spinal cord produce messages and carry these messages to the muscles and endocrine glands to create a response with afferent groups. The main internal neurons that compile, collect, combine, and coordinate all these action-reaction processes are called connecting groups[1]. The entire reaction occurs in less than a second, and such a high speed is possible by transmitting information very quickly in the nervous system[43].

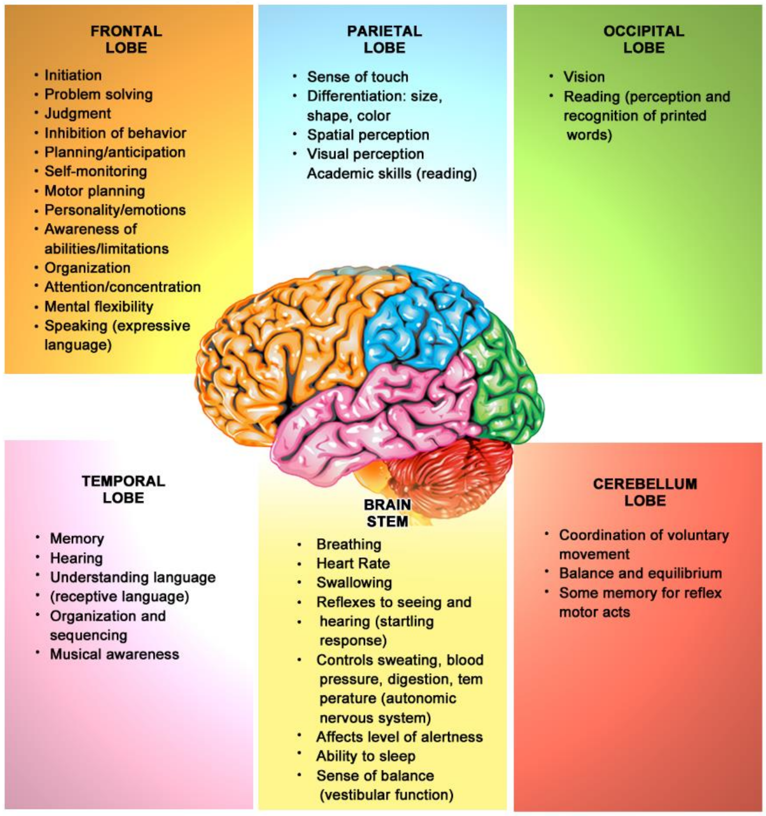

Figure 5: Cognitive Skills of the Brain[41].

Each cerebral hemisphere of the human brain is divided into 4 lobes which have different cognitive skills as seen in Figure 5: (1) '*Frontal lobe*': responsible for reasoning, emotions, judgment, and voluntary movement; (2) '*Temporal lobe*': contains centres of hearing, smells, and memory; (3) '*Parietal lobe*': responsible for touch and spoken language ability; (4) '*Occipital lobe*': the region at the back of each cerebral hemisphere that is responsible for centres of vision and reading ability[20].

As the intensity of the stimulus increases, the excitation frequency of the neuron increases, and the intensity of the stimulus is felt more strongly. It can no longer be stimulated after a certain point when the stimulus intensity is too high. It is thought that there will be a significant change in vision, hearing, and body senses, especially in the process of being affected by GSs in the cerebral cortex. Because more sensitive behaviours of the body and parts that require muscle coordination are possible by activating the parts of the body corresponding to those regions through electrical stimulation of different parts of the motor cortex[1,42]. Lesions caused by damage to the temporal cortex impair the ability to distinguish between different perceptual stimuli and reduce the ability to perceive partial types of visual information[42].

As stated in the article of Babayev and Allahverdiyeva[16], the right hemisphere is the brain lobe most affected by the storm. So, what are the functions of the brain lobes? The cerebral hemispheres have a diagonal relationship with the body: the left cerebral hemisphere receives sensations from the right half of the body and moves the right side while the right hemisphere receives the sensations from the left half of the body and moves the left side. The difference between the two hemispheres is that the right hemisphere is superior in cognitive functions that require more visual-locational-spatial material processing while the left hemisphere is superior in verbal skills, in the left-brain hemisphere there are regions and structures related to language functions, including some regions in the parietal, temporal and frontal lobes[44].

3. Short- and Long-term Changes in the Neurophysiological Status of Pilots Depending on the Geomagnetic Storms

3.A. SHORT-TERM CHANGES IN THE NEUROPHYSIOLOGICAL STATUS OF PILOTS

In the ground-based experiments, firstly, functional areas of the cerebral cortex are affected such as indistinct localized headaches, disbalance of integrative subcortical systems, indisposition, and weakness were recorded for the majority of volunteers during periods of strong geomagnetic disturbances which influence first the central nervous system as 'Brain' and 'Spinal cord'. Secondly, the vegetative nervous system is being affected. During these damages, blood viscosity increases distinctly while the blood flow slows down, and the erythrocytes became adhesive[16,45]. When we compare the calm and disturbed days of GA, myocardial infarction, acute cerebral insults, angina pectoris, and cardiac arrhythmia increase in the periods of GSs[45].

The intensity of GSs during EEG experiments will be different depending on the seasonal changes as mentioned by Kay[46] and Halberg[47]. Yip et al.[48] have found out that the suicide rate reaches its peak during spring and summer, however, Partonen et al.[49] claimed that suicide coincides with the times of maximum geomagnetic disturbance that reaches the peak in spring and autumn seasons. Novik[50] mentioned that the arterial blood pressure, respiratory rate, and electrocardiographic features continue their steady condition while the coherence function values of the EEG electrical oscillations in the frontal polar and occipital locations of the brain decrease during the moderate GS or within 24h after the storm. These changes are much in evidence in the 4-7 Hz range which corresponds to θ rhythm. The influence of heliophysical, cosmophysical, and meteorological factors on the CNS and CVS in general and on cognitive functions will allow us to implement a comprehensive approach to studying the adaptive mechanisms of the body[51].

As for the pilots, all these damages we mentioned above will be stronger as they are closer to the CR and high-speed SWs. In a short-term period (e.g., during GSs and following maximum a week after the storm), decision-making and judgment problems, abnormal attitudes (e.g., anger, fearlessness, temerity, self-confidence, etc.), decreasing problem-solving abilities, organization capabilities, and instantaneous and correct decisions which are very important for pilots, mental flexibility is affected in the frontal lobe; disability in the differentiation of shapes, colours and sizes, decreasing of visual perception in parietal and occipital lobes; and organization disabilities in the temporal lobe are the main damages in the brain. Balance and equilibrium discoordination in the cerebellum lobe is another important problem for pilots. Weakness, malaise, irregularity in movement functions, unspecified regional headaches, misbalance, heart infarction, seizure situations, and mental disorders due to the nervous system; perception error, cognitive weakness in reading and interpreting flight instruments, reaction time prolonged, and mental confusion and incapacity are the main short-term changes for the pilots during the fight. So, what kind of permanent damage will these seemingly short-term harmful effects cause in the long-term?

3.B. LONG-TERM CHANGES IN THE NEUROPHYSIOLOGICAL STATUS OF PILOTS

All these short-term ruins on pilots mean constant exposure to external forces, especially for pilots who fly long distances and continuously. Geographical latitudes have very important effects on flight as well, particularly pilots flying at high latitudes will be exposed to all these effects much more than flying pilots in the mid-latitudes or lower latitudes. These short-term effects are likely to cause serious brain and muscle diseases in the long-term periods, whether in civil aviation or military pilots. However, the effects of CR on pilots should not be confused with other basic flight diseases such as hypoxia, acceleration forces, spatial disorientation or volatile vertigo, fatigue, shift-lag, jetlag, thermal stress, dehydration or water loss, and altitude drunkenness.

In the long term, short-term harmful effects will be more likely to develop cancers of the brain, testis, bladder, breast, colon, melanoma, and Hodgkin's type[7]. It can even trigger Alzheimer's and dementia diseases. In addition, milder conditions such as hypoglycaemia, stroke, epileptic seizures, insomnia, stomach bleeding, appendicitis, hernia, asthma, and severe spinal pains can lead to it.

4. Discussion of the Effects of Geomagnetic Storms on Human Brain Functions and Neurophysiological Status of Pilots

In the previous sections, firstly, a brief history of aviation psychology was given, and it was stated how important neurophysiology is in researching the cognitive and personality psychologies of pilots. In the second part, the structure of GSs is briefly explained and it is mentioned which regions of the human brain are affected by these storms in short- and long-time changes. In this section, we will discuss how these storms will affect the specified regions of the brain.

For a pilot to fly in a situation where environmental influences are very strong, he/she must have a clear mind, strong muscle coordination, the ability to master cognitive behaviours such as perception, memory, and information processing, and personality traits such as courage, self-confidence, strong anger control, and able to cope with risk situations. These situations are among the characteristics that both groups should have, whether they are military or civil aviation pilots; however, basic meteorological reasons such as rain, snow, fog, and low-cloud height make the job of pilots very difficult in flights. In addition, a much more dangerous situation is the exposure of the pilot to high radiation. *Flight personnel are in the radiation employee category and the radiation limit is 20 mSv (millisievert)/year. This value is 1 mSv/year for the public. The limit to which flight personnel flying 600 hours a year will be exposed is 1.5 mSv*[52]. However, this risk is much higher for flight personnel flying around 1000 hours at high geographic latitudes. In the studies carried out, an annual exposure of 5 mSv within 20 years causes an increase of 0.1-0.4% in the risk of cancer, and this rate increases to 0.6 when the exposure period is 30 years. 50% of the radiation that humans are exposed to comes from radon in nature while only 10% comes from CR. The harmful effects of ionizing radiation (due to radon) were once limited to high-energy X-rays, radium, and other natural sources of radiation used for diagnostic and therapeutic purposes. Today, the main sources of radiation are nuclear reactors, cyclotrons, linear accelerators, licensed sources of cobaltite and caesium used in cancer treatment, and numerous artificial radioactive materials used in medicine and industry on the ground[53].

The rate of reception (dose rate) of radiation is expressed as radiation dose/unit time. While no effect is observed at the lowest naturally occurring radiation dose on the Earth (1-2 mSv/year), the probability of measurable effects increases in parallel with the dose rate and the total dose. Intermittent low-dose radiation must reach very high doses to be effective while a distinct effect is observed at a single and high dose of mSv. High doses cause immediate somatic effects, while low doses have a late somatic and a long-term genetic effect. The body area exposed to radiation is also important. The total dose that the entire human body can take without death is approximately $2x10^3$ mSv. When the total dose reaches $4.5x10^3$ mSv, the probability of death increases to 50%. If the total dose taken by the body exceeds $6x10^3$ mSv in a very short time, it becomes fatal[53]. It can be said that it is almost impossible to escape this radiation effect in a severe GS. We will discuss below how the above-mentioned brain regions are affected when exposed to such radiation:

1. In very severe GSs, fatigue, malaise, and local headaches of unknown origin are the most common situations.

2. As the cerebral cortex is affected, irregularity and balance disorder will begin in movement functions. Although GSs are one of the causes of organic problems mentioned in the 1st and 2nd items, it is shown that the most important and main effects causing these problems are hypoxia, acceleration forces, spatial disorientation, fatigue, shift-lag, jetlag, thermal stress, and dehydration. In '*hypoxia*', after 3500-4000 meters of altitude, voluntary movements become difficult (lack of muscle coordination). The tendency to cramp and contract awakens, the reflex slows down, physical-psychic chronic fatigue begins, and intellectual activity (attention, memory, reasoning) is reduced. Decreasing insight, increased self-confidence, unnecessary risk-taking, recklessness, stubbornness, and aggressive reactions occurs psychologically while headache, depression, absent-mindedness, erroneous decisions, and sleepiness are seen in the cognitive situation. Visually blurred vision, reduced night vision, and difficulty in colour discrimination will occur; additionally, physical shortness of breath, hyperventilation (excessive breathing), headache, dizziness, nausea, paraesthesia, tachycardia, and fatigue will be seen. There is a tendency to inadequacy in comprehension, irregularity of harmony and synergy in movements, and increased confidence (euphoria), which is called '*altitude drunkenness*'[7]. In case of acceleration, visual field darkening, loss of consciousness, and convulsive syncope may occur in pilots with insufficient physical conditions or who cannot perform anti-G maneuvers properly. In jet planes, in cases where blood is drawn from the brain to the lower tissues, that is, a decrease in blood pressure at the brain level, the pilot cannot control the aircraft for at least 15-30 seconds depending on the brain hypoxia. In addition, cognitive disorders such as confusion, loss of awareness, euphoria, amnesia, and decision-making difficulties will be seen[7].

The orientation of man in space is provided by the coordination of four systems (*visual, auditory, vestibular, and proprioceptive*). The share of perceptions in balance and position is 79% in visual perception, 5% in the deep sense, 15% in the vestibule and 1% in the auditory system. The disorientated pilot is not just in a position of perception error; they also show cognitive weakness in reading and interpreting flight instruments and making correct decisions; reaction time is prolonged, and mental confusion and incapacity occur. This situation is called '*spatial disorientation*'[7]. In the case of jetlag, somatic, cognitive, and psychological disorders occur. In somatic disorders, loss of appetite or feeling of hunger at inappropriate times, fatigue, intestinal laziness (constipation), insomnia or sudden sleepiness are seen. Cognitively, there are deficits in attention, concentration, judgment-memory, distortion of time and distance perception, prolongation of reaction time, and delay in comprehension and learning functions. Prominent situations among psychological problems are anxiety, irritability, irritability, depression, and sometimes euphoria. In the case of shift-lag, changing the usual work-rest period affects body temperature, blood sugar level, and mental working capacity. In this case, fatigue, insomnia, digestive system and other somatic complaints, and general malaise are observed[7].

3. If the incoming radiation has a significant effect only on the right cerebral cortex, when we consider that the right hemisphere is responsible for cognitive functions such as visual-locational-spatial material, the visual, locational, and spatial computation ability which is the main rule of flight, will directly be affected. In this case, the pilot may forget important calculations or miscalculate, and lose the ability to evaluate events carefully. Here, if the cognitive and personality characteristics of the pilot are sufficiently developed, he/she will have the ability to minimize these effects. In contrast to this, if he/she is unable to reduce these effects, that is, he/she does not have the capacity for emotional regulation to overcome his/her fears, he/she may hesitate, panic, and fail to fulfil his duties. Great nervous tension can also distort the sense of time of the pilot. The physiological basis of what we psychologically call fear and panic is the restrictive state of the cerebral hemispheres. This situation corresponds to various passive-defensive reflex levels[4].

4. When the nervous system, which brings information to the brain, is affected[1]

a. Heart infarction, seizures, and mental disorders related to the nervous system are seen, and these disorders will become even more disturbing as the effect of radiation gets longer.

b. In situations that require an urgent and sudden decision, it will lead to an increase in blood pressure and heart rate, increase in respiratory rate, dilation of the pupil, increase in sweating, decrease in salivation, and more energy emerges by increasing in the amount of sugar in the blood, increase in blood coagulation factors, increase in blood flow from digestive organs to the brain and striated muscles.

5. Changes in vision, hearing, and body senses will be important in the cerebral cortex, especially in the process of being affected by GSs. In such cases, the motor cortex will be effective in the parts of the body that require more sensitive behaviours and detailed muscle coordination.

6. Damage to the temporal cortex will result in lesions that will impair the ability to recognize distinctions between different perceptual stimuli and reduce the ability to perceive partial types of visual information.

One by one, careful, and detailed tests must be carried out from the very beginning on all these affected areas, which we have listed as items. Perhaps, other than these determined regions, different kinds of results may be encountered in different sensory regions. This research has the potential to be long-term research.

5. Conclusions and Future Work

Studies on the effects of GSs on military and civil aviation psychology started to gain momentum in 2013 mainly in the United Kingdom, however, a research laboratory has not yet been established for the possible effects of GSs on the volunteers and have not been investigated yet in many countries which are the members of the ICAO. In addition, the countries located in the middle latitudes cannot be experienced directly the GS effect as it is experienced by pilots in high latitudes and polar regions, therefore laboratory studies should accelerate as soon as possible for the middle/low latitude geographic regions. In the paper of Aksen et al.[28], it is shown that the accidents that may be geomagnetic in origin accounted for 26.36% of the total accidents which coincide with the days of GSs. What kind of work can be done in the future:

1. Firstly, a laboratory environment where all the physical parameters of the GS will be established, and free from fundamental and other disruptive effects, should be set up with researchers from the different fields of science and engineering, and clinicians. At this initial stage, only the effect of the GS will be determined. Afterwards, in order to

make the study more comprehensive, the relevant experiment must be carried out separately with environments such as a low-pressure room, centrifuge laboratory, and air-conditioning laboratory to simulate real flight conditions, and necessary comparisons should be made. Relax and hyperventilation conditions must be taken into account separately for the volunteers in addition to keeping the eyes of the volunteers open and closed throughout these tests as a part of the classification.

2. *Initial Classification*: Volunteers should be selected from both military and civil aviation pilots according to the cognitive and personality psychology test results, different ages, genders, and physical conditions, etc.

3. *Second Classification*: A separate classification should be made according to the aircraft types used by the volunteers.

4. *Third Classification*: Volunteers should be tested in environments corresponding to different GS intensities and a separate classification should be made according to their reactions when exposed to different GS intensity values between 0-9.

5. *Fourth Classification*: Depending on the persistence of the effects of GSs from a few hours to a few days, a separate classification should be made according to the time interval they are exposed to the GS effect.

6. Immediately after the end of each experiment, the pilots should undergo a neurophysiological test with the necessary medical and psychological examination. Thus, the psychological and physiological changes seen in pilots can be observed before and after flight being tested. In addition to these experiments, the instantaneous physiological effects stay out of GSs during the flight should be considered as other disturbing effects.

The pilot and cabin crew flying at high latitudes will experience the full impact of the GS; whereas pilots and cabin crew flying in mid-latitudes can only be tested in a laboratory environment and their physiological reactions to these effects can be measured in a laboratory as well. This hypothesis is of particular importance as these experiments will be applied for the first time in the aviation psychology literature.

Conflicts of Interest Statement

I am the only author of this paper, and this is why I wish to confirm that there are no known conflicts of interest associated with this publication.

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References

1. Cüceloğlu D. *Human and Behaviour, Basic Concepts of Psychology (36th Ed.)*. Remzi Publications, İstanbul, Turkey. 2000. ISBN: 978-975-14-1869-2.
2. Biochemical Methods and Techniques of Neuroscience. Accessed August 1, 2023. https://neuros.creative-biolabs.com/.
3. Introduction to Neurophysiology. Accessed August 1, 2023. https://www.physio-pedia.com/.
4. Gagarin Y, Lebedev V. *Space and Psychology* (Trans. Sibel Özbudun), Süreç Publications, İstanbul, Turkey. 1984.
5. Ragan KM. The Warfighters of Today: Personality and Cognitive Characteristics of Rated Fighter Pilots in the United States. *Ph.D. Thesis*. Florida State University Library, Florida, USA. 2010.
6. Koonce JM. A Brief History of Aviation Psychology. *Human Factors*. 1984; 26(5): 499-508. doi: 10.1177/001872088402600050.
7. Çetingüç M. *Aviation and Space Psychology*. Nobel Academic Publications, İstanbul, Turkey. 2016. ISBN: 978-605-320-495-4.
8. Cannon PS, Angling M, Barclay L, Curry C, Dyer C, Edwards R, et al. *Extreme Space Weather: Impacts on Engineered Systems – a Summary*. Royal Academy of Engineering, London, UK. 2013a. ISBN: 1-903496 96-9.
9. Cannon PS, Angling M, Barclay L, Curry C, Dyer C, Edwards R, et al. *Extreme Space Weather: Impacts on Engineered Systems and Infrastructure*. Royal Academy of Engineering, London, UK. 2013b. ISBN: 1-903496-95-0.
10. Ersoy E, Karal Ö. Artificial Neural Networks and Human Brain. *ITOBIAD*. 2012; 1(2): 188-205. https://dergipark.org.tr/tr/pub/itobiad/issue/8760/109318.
11. An H, Zhou Z, Yi Y. Opportunities and Challenges on Nanoscale 3D Neuromorphic Computing System. *Conference Paper*, 2017 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI). 2017. 10.1109/ISEMC.2017.8077906.
12. Types of Neuroglia. Accessed August 1, 2023. https://qbi.uq.edu.au/.
13. The Structure of Neuron. Accessed August 1, 2023. https://www.enchantedlearning.com/.
14. Autonomic Nervous System of Human. Accessed August 1, 2023. https://www.simplypsychology.org/.
15. Functional Areas of the Cerebral Cortex including Motor Cortex (Areas 3 and 12) and Temporal Cortex (Area 2), and the Cerebellum. Accessed August 1, 2023. https://www.dana.org/article/neuroanatomy-the-basics/.
16. Babayev ES, Allahverdiyeva AA. Geomagnetic Storms and Their Influence on the Human Brain Functional State. *Revista CENIC Ciencias Biológicas*. 2007a; 36: 1-8. ISSN: 2221-2450 (Online).
17. Büyükgöze S. Non-invasive BCI Method: EEG-Electroencephalography. *Conference Proceedings Paper*, International Conference on Technics, Technologies, and Education ICTTE 2019, Bulgaria, 2019: 1-8. ISSN: 1314-9474.
18. Nagel S. Towards a Home-Use BCI: Fast Asynchronous Control and Robust Non-Control State Detection. *Ph.D. Thesis*. Tübingen, Germany. 2019; pp.156.
19. The Five Most Common EEG Bands and Their Frequency Ranges. Accessed August 1, 2023. https://neurosky.com/.
20. Babayev ES, Allahverdiyeva AA. Effects of Geomagnetic Activity Variations on the Physiological and Psychological State of Functionally Healthy Humans: Some Results of Azerbaijani Studies. *Adv. Space Res.* 2007b; 40: 1941-1951. doi: 10.1016/j.asr.2007.02.099.
21. Timoçin E, Ünal İ, Göker ÜD. A Comparison of IRI-2016 foF2 Predictions with the Observations at Different Latitudes During Geomagnetic Storms, *Geomagn. Aeron.* 2018a; 58(7): 846-856. doi: 10.1134/S0016793218070216.
22. Timoçin E, Ünal İ, Tulunay Y, Göker ÜD. The Effect of Geomagnetic Activity Changes on the Ionospheric Critical Frequencies (foF2) at Magnetic Conjugate Points. *Adv. Space Res.* 2018b; 62: 821-828. doi: 10.1016/j.asr.2018.05.035.
23. Göker ÜD. The Importance of Heat Conduction and Viscosity in Solar Corona and Comparison of Magnetohydrodynamic Equations of One-Fluid and Two-Fluid Structure in Current Sheet. *Sun Geosph.* 2008; 3(1): 52-56. ISSN: 1819-0839.
24. Göker ÜD. Magnetohydrodynamic Study of Shock Waves in the Current Sheet of a Solar Coronal Magnetic Loop. *New Astron.* 2012; 17: 130-136. doi: 10.1016/j.newast.2011.06.010.
25. Göker ÜD, Gigolashvili MSh, Kapanadze N. Solar Spectral Irradiance Variability of Some Chromospheric Emission Lines Through the Solar Activity Cycles 21-23. *Serb. Astron. J.* 2017a; 194: 71-86. doi: 10.17134/khosbd.477241.
26. Göker ÜD, Singh J, Nutku F, Priyal M. Temporal Variations of Different Solar Activity Indices

Through the Solar Cycles 21-23. *Serb. Astron. J.* 2017b; 195: 59-70. doi: 10.2298/SAJ1795059.

27. Göker ÜD. Temporal Modelling of Chromospheric Emission Lines for Solar Spectral Irradiance Through the Solar Activity Cycles 21- 23, *C. R. Acad. Bulg. Sci.* 2018; 71(11): 1511-1519. doi: 10.7546/CRABS.2018.11.10.
28. Aksen U, Göker ÜD, Timoçin E, Akçay Ç, İpek M. The Effect of Geomagnetic Storms on Air Crash Investigations Between the Years 1919-2023. Submitted to *Adv. Space Res., in review*. 2023.
29. The Sketch of Geomagnetic Storm and Interaction with Earth. Accessed August 1, 2023. https://www.clearias.com/geomagnetic-storm/.
30. Coronal Mass Ejections. Accessed August 1, 2023. https://www.space.com/coronal-mass-ejections-cme.
31. Coronal Holes. Accessed August 1, 2023. https://earthsky.org/space/aurora-alert-coronal-hole-jan-3-and-4-2017/.
32. O'Brien TP, McPherron RL. An Empirical Phase Space Analysis of Ring Current Dynamics: Solar Wind Control of Injection and Decay. *J. Geophys. Res.* 2000; 105: 7707-7719. doi: 10.1029/1998JA000437.
33. Wang CB, Chao CK, Lin C-H. Influence of the Solar Wind Dynamic Pressure on the Decay and Injection of the Ring Current. *J. Geophys. Res.* 2003; 108(A9): 1341-1354. doi: 10.1029/2003JA009851.
34. Zhao H, Zong QG, Wei Y, Wang YF. Influence of Solar Wind Dynamic Pressure on Geomagnetic Dst Index During Various Magnetic Storms. *Sci. China Tech. Sci.* 2011; 54(6): 1445-1454. doi: 10.1007/s11431-011-4319-y.
35. Burton RK, McPherron RL, Russell CT. An Empirical Relationship Between Interplanetary Conditions and Dst. *J. Geophys. Res.* 1975; 80: 4204-4214. doi: 10.1029/JA080i031p04204.
36. International Space Environment Service. Accessed August 1, 2023. http://www.ises-spaceweather.org/.
37. Gulyaeva TL, Stanislawska I. Derivation of a Planetary Ionospheric Storm Index. *Ann. Geophys.* 2008; 26: 2645-2648. doi: 10.5194/angeo-26-2645-2008.
38. National Transportation Safety Board. *Risk Factors Associated with Weather-Related General Aviation Accidents*. Safety Study NTSB/SS-05/01. Washington, DC. 2005.
39. Göker ÜD, Yazıcı M, Balcı G, Köksal Ö, Şengelen HE. The Statistical Analysis of Air Crash Investigations, *J. Def. Sci.* 2021; 2(40): 1-32, doi: 10.17134/khosbd.1000317.
40. Mertens CJ, Kress BT, Wiltberger M, et al. Geomagnetic Influence on Aircraft Radiation Exposure During a Solar Energetic Particle event in October 2003. *Space Weather*. 2010; 8: S03006- S03022. doi:10.1029/2009SW000487.
41. Cognitive Skills of the Brain. Accessed August 1, 2023. https://horizontbi.com/cognitive-skills-of-the-brain/.
42. Carlson NR. *Foundations of Behavioural Neuroscience (9th Ed.)*. Pearson New International Edition, Chicago, USA. 2013. ISBN: 0205968090.
43. Gegenfurthner KR. *Brain and Perception* (Trans. Barış Konukman), İnkılâp Publications, İstanbul, Turkey. 2005.
44. Öktem Ö. *Introduction to Behavioural Neurophysiology*. Nobel Medicine Publications, İstanbul, Turkey. 2013. ISBN: 9789754209693.
45. Gurfinkel II, Kuleskova VP, Oraevski VN. Assessment of the Effect of a Geomagnetic Storm on the Frequency of Appearance of Acute Cardiovascular Pathology, *Biofizika. J. Biophys.* 1998; 43(4): 654-658. PMID: 9783073.
46. Kay RW. Geomagnetic Storms: Association with Incidence of Depression Measured by Hospital Admission. *BJPsych.* 1994; 164(3): 403-409. doi: 10.1192/bjp.164.3.403.
47. Halberg F, Cornelissen G, Pankseep J, Otsuka K, Johnson D. Chronemics of Autism and Suicide. *Biomed. Pharmacother.* 2005; 59 (Supp.1): 100-108. doi: 10.1016/s0753-3322(05)80017-4.
48. Yip PSF, Chao A, Ho TP. Are Re-examination of Seasonal Variation in Suicides in Australia and New Zealand, *J. Affect. Disord.* 1998; 47: 141-150. doi: 10.1016/S0165-0327(97)00135-3.
49. Partonen T, Haukka J, Viilo K, Hakko H, Pirkola S, et al. Cyclic Time Patterns of Death from Suicide in Northern Finland. *J. Affect. Disord.* 2004; 78: 11-19. doi: 10.1016/s0165-0327(02)00236-7.
50. Novik O. Influence of Space Weather on the Bioelectrical Activity of the Human Brain. *Electromagnetic Geophysical Fields* (Chapter 6), Springer Nature Switzerland AG. 2019; 91-103.
51. Pavlov KI, Syrtsev AV, Mukhin VN, Archimuk AN, Mikheeva EA, et al. The Effect of Environmental Factors on the Cognitive Functions of Cadets at a Military Institute, *Izv. Atmos. Ocean. Phy.* 2019; 55(10): 1465-1487. doi: 10.1134/S0001433819100086.

52. International Commission on Radiological Protection. Accessed August 1, 2023. http://www.icrp.org/icrpaedia/limits.asp.

53. Berkow R. *The Merck Manual of Diagnosis and Therapy (16th Ed.)*, Merck Research Laboratories, MERCK & CO., INC. Rahway, N.J. 1992. ISBN: 13: 9780911910162.