**Bilişsel Fonksiyonlara Dayalı Nöro-Geribildirim Protokolü**

**A Neurofeedback Protocol for Cognitive Functions**

**Özet**

aritmetik, hafıza ile ilgili, mantıksal ve ahlaki problemleri çözme süreçleri.

Nörogeribildirim uygulamalarında, bireyin beyin aktivitesi bir görev süreci boyunca izlenir ve bireyin performansını tahmin edebilmek için başta makine öğrenmesi olmak üzere çeşitli modeller kullanılır. Çalışmanın ilk kısmında, farklı bölgelerden toplanan elektrofizyolojik veriye dayanarak kullanıcıların çözdüğü problem tipini en iyi temsil eden elektrotlar seçildi. İkinci kısımda ise seçilmiş kanallardan elde edilen verilere dayanarak kullanıcıların üzerinde düşündükleri yeni bir setteki problemleri çözme sürecinde hangi bilişsel yetilerini kullandıklarını geri bildirim olarak sağladık.

**Abstract**

**Giriş**

Farklı problemleri çözmek mantık, hafıza, yaratıcılık ve hesaplama gibi farklı bilişsel süreçleri gerektirir. Bu süreçler beynin özelleşmiş kısımlarında farklı genlikte ve frekansta sinyaller olarak okunur. Sinyal örüntülerinin tespit edilmesi, lokalizasyonu ve sınıflandırılmasında makine öğrenme yöntemleri kullanışlı bir araçtır. Literatürde dikkat, uyanıklık seviyeleri ve duygu durumu gibi mental durumları sınıflandıran başarılı sonuç elde etmiş çalışmalar bulunmaktadır **[1-3]**. Ancak farklı bilişsel yetileri kullanarak matematiksel, sözel, hafızaya dayalı problemleri düşünmek ve bu konulardaki sorulara cevap verme süreçleri için sınıflandırma yöntemine sık rastlanmamaktadır.

Nörogeribildirim uygulamasında, bireyin beyin aktivitesi tüm problem çözme süreci boyunca izlenir ve bireyin performansını tahmin edebilmek için makine öğrenimi algoritmaları kullanılır. Algoritma bireyden gelen gerçek zamanlı veri ile eğitilerek daha sonra bu sinyaller bireyin kendi verileriyle karşılaştırılır. Bireylerin performansı, çeşitli grafikler veya göstergeler aracılığıyla kendilerine sunulurken bu çıktılarda manipülasyon yapmalarına olanak sağlanır. Bu yöntem iki özelliği nedeniyle standart nörogörüntüleme yöntemlerinden ayrılır. İlki, gerçek zamanlı olarak eğitilen modeller sayesinde kullanıcının anlık bilgilendirilmesi, ikincisi ise toplanan sinyal üzerinde varsayımsal olmayan bir algoritmayla çalışarak kişiselleştirilmiş sonuçlar sağlayan veriye dayalı bir sistem olmasıdır. Nörogeribildirim çalışmaları fMRG, MEG, EEG gibi cihazlar kullanılarak yapılmaktadır. Bu çalışmada, zamansal çözünürlüğü ve erişilebilirliği açısından optimal yöntemlerden biri olması gerekçesiyle EEG kaydı kullanacağız **[4-6]**. Her tür bilişsel fonksiyonun işlendiği nöral gruplar farklı frekanslarda senkronize olduklarından **[7-10]** topladığımız elektrofizyolojik veriyi frekans kanalları bazında analiz edeceğiz .

Çalışmanın ilk kısmında, 14 farklı bölgelerden toplanan veriye dayanarak kullanıcıların çözdüğü problem tipini en iyi temsil eden bilgilendirici elektrotlar seçilecektir. Katılımcıların verilen problem setinde kullanmaları beklenen bilişsel yetiler 4 sınıfta gruplanmıştır: aritmetik, hafıza ile ilgili, mantıksal ve ahlaki problemleri çözme süreçleri. İkinci kısımda ise seçilmiş kanallardan elde edilen verilere dayanarak kullanıcıların üzerinde düşündükleri yeni bir setteki problemleri çözme sürecinde hangi bilişsel yetilerini kullandıklarını geri bildirim olarak sağlayacağız.

**Yöntem**

**Deney**

Deney, MATLAB’ta Psychtoolbox kullanılarak dizayn edilmiştir. Deneyin ilk iki kısmı göz önünde bulundurulduğunda, her kategori için, toplam 10 soru bulunmaktadır. Soruları okuma sürecini, deneyi olumsuz etkileyebileceği için sorular olabildiğince kısa tutulmaya çalışılmıştır. Böylelikle, okuma sürecinden kaynaklanan beyin sinyaller minimuma indirgenmiştir. Sorularda zaman sınırlaması bulunmamaktadır: katılımcı o anda çözmekte olduğu soruyu istediği zaman cevaplayabilir. Deneyde kullanılan soru kategorileri belirtildiği gibidir:

*Hafıza Soruları;* bu sorular katılımcılara bir konuyu veya bir anıyı hatırlatmak amacıyla sorulmuş sorulardır. Deneyde hem uzun süreli bellek hem de kısa süreli bellek soruları bulunmaktadır.

*Ahlaki Sorular;* bu sorular deneklerin zihninde ahlaki ve manevi ikilemler oluşturmak amacıyla sorulmuş sorulardır. Diğer kategorilerdeki sorularla karşılaştırıldıklarında, bu sorular genel olarak daha uzundur. Bunun sebebi ikilemlerin bulunduğu durumun deneklere anlatılmasının uzun sürmesinden kaynaklanmaktadır. Durumun deneke net bir şekilde anlatılması denekin cevap vermesini kolaylaştırmaktadır.

*Mantık Soruları;* bu kategorideki sorular sözel mantık üzerine sorulmuştur. Ayrıca, bu kategorideki sorular birbiriyle cevapları haricinde aynıdır, katılımcılar rastgele verilen harfler kümesiyle anlamlı bir kelime oluşturmalıdır.

*Aritmetik Sorular;*  bu kategoride deneklere oldukça yalın bir matematiksel sorular sorulmuştur. Bu sorular genel olarak çarpma ve bölme işlemleri içermektedir.

Bütün bu sorular rastgele sırayla sorulmakta ve veri kaydı EPOC+ cihazının sunduğu arayüz ile yapılmaktadır.

**Ön işleme**

Gürültüden arındırılmış, belirgin sonuçların elde edilmesi için toplanılan veriye çeşitli sinyal işleme yöntemleri uygulanmalıdır. Veri, bu yöntemlerle istenmeyen çevresel ve fizyolojik temelli gürültüden temizlenip, araştırmaya uygun bir hale getirmelidir. Bu sebeple, veriye öncelikle Bağımsız Bileşen Analizi uygulanmalıdır. Bu uygulamanın sebebi gözlerin deney süreci boyunca açılıp kapanmasıdır. Göz kaslarının bu hareketi, beyinde nöral aktivite oluşturup alınan verilerden doğru çıkarımlar yapılmasını büyük ölçüde engellemektedir. Dolayısıyla bu istenmeyen sinyaller, veriden ayıklanmalıdır. Bu sürece en uygun yöntem Bağımsız Bileşen Analizidir. Adından da anlaşılabileceği gibi veriyi bağımsız bileşenlerine ayıran bu yöntem kullanılarak göz kaslarını hareketleri sebebiyle oluşan sinyaller kolaylıkla saptanabilir ve silinebilir.

Bu süreçten sonra, sinyale yönsemeyi giderme (detrending) işlemi uygulanmalıdır. Böylelikle verideki uç noktalar temizlenebilir ve veri başlangıç noktasından ortaya çıkması suretiyle yeniden şekillendirilir.

Bundan sonra, sinyale "bandpass" filtreleme uygulanmalıdır. Bu sayede veri, sonuçlar için bir etkisi olmayan yüksek frekanslı ve düşük frekanslı sinyallerden temizlenir.

Bu adımdan sonra, sinyale Hızlı Fourier Dönüşümü uygulanmalıdır. Bu yolla veri, zaman ekseni yerine frekans ekseni içerisinde incelenebilecek duruma gelir. Böylelikle veri, bilişsel sinirbilim alanında hangi mekanizmalara gösterge oluşturduğu kısmen anlaşılabilmiş frekans kategorilerine göre sınıflandırılabilir. Kullanacağımız sinyal frekans aralıkları, 4-8 Hz, 8-13 Hz, 13-30 Hz, 30-90 Hz frekans bantlarına karşılık gelen, theta, alfa, beta ve gama olacaktır. Her frekans farklı bir bilişsel aktiviteye denk geldiğinden bu işlem sayesinde farklı bilişsel fonksiyonlar hakkında bilgi sahibi olmayı hedefliyoruz.

Aktif olan nöronlar gama aralığına yakın sinyaller üretirken, bilinçli bir işlemde aktif olarak rol almayan nöronlar delta aralığına yakın sinyaller üretir. Alfa aralığının (8-13 Hz), dikkat yükü ve beyin aktivitesinin kısıtlanması gibi işlevler ile ilgili olduğu gözlemlenmiştir (Palva ve Palva, 2007). Beta aralığının ise, tepeden-aşağıya dikkat kontrolü ve devam etmekte olan zihinsel işlevlerin sürdürülmesi ile alakalı olduğu bulunmuştur (Fries vd., 2001). Gama aralığı aktivitesi ise; duyusal verilerin işlenmesi, ilgi gösterme ve zihinsel işlevlerin yönetici kontrolü gibi bilişsel fonksiyonlar ile ilgili olduğu anlaşılmıştır (Fries vd., 2001).

**Analiz**

Deneyin eğitim kısmından elde edilen veriler ikinci kısımdaki soruları değerlendirme sürecinde elektrofizyolojik verilerin analizinde kullanılmıştır. Katılımcılar, karşılaştıkları her yeni soru tipi için 4 tabanlı bir sonuç hesaplanmıştır. Kullanılan elektrot sayısı ilk kısımla aynıdır. Toplanan veriler, PCA sonucunda seçilen pozisyonlar baz alınarak her yeni soru için ‘aritmetik, etik, bellek, mantık’ sorularıyla karşılaştıkları zaman belirleyici kanallarda ne oranda aktivasyon değişikliği gösterdikleri hesaplanılarak ekranda bar grafiği olarak gösterilmiştir.

**Sonuçlar**

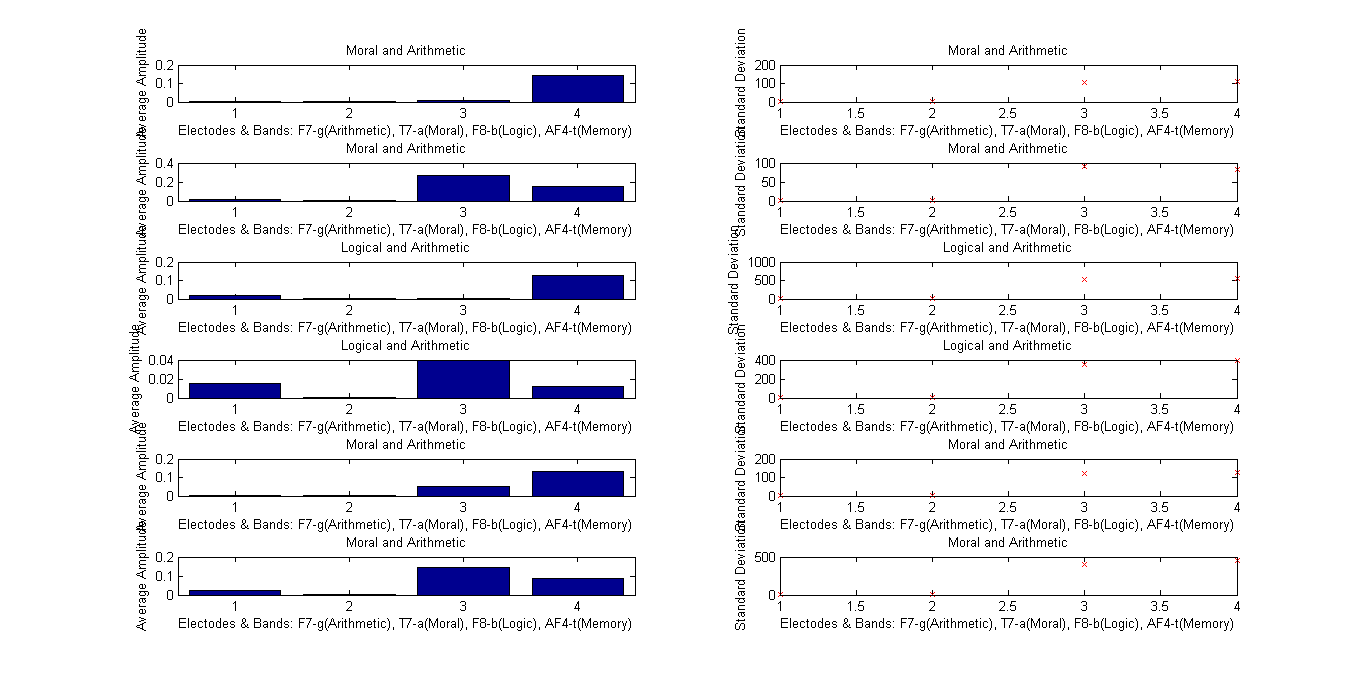
**İlk dört alan için pozisyon belirlediğimiz kısımda PCA scoreları neler? Rapor edilmesi gerek.**

EPOC+ cihazında 14 farklı elektrot ve toplamda 6 farklı problem kombinasyonu olduğu için toplamda 84 farklı doğruluk değeri hesaplanmaktadır. Deneyin şu anki durumunda, her soru için, deneyden toplam 40 farklı değer elde edilmektedir. Bu 40 farklı değer, bir diğer deyişle veri noktası, sınıflandırılmalıdır. Dolayısıyla veri iki ayrı kümeye ayrılmıştır; birinci küme eğitim kümesidir ve 32 veri noktası bulundurmaktadır. İkinci küme ise test kümesidir ve 8 veri noktası bulundurmaktadır. Test verilerinin, eğitim verilerine, KNN algoritması kullanılarak sınıflandırılmasıyla elde edilen doğruluk oranları, incelenen elektrodun bu kategorideki soruların ayrıştırılması için kullanılıp kullanılamayacağını saptamak için kullanılmaktadır.

Table 1. KNN Algoritmasından Elde Edilen Doğruluk Oranları

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Aritmetik - Ahlaki | Aritmetik - Mantık | Aritmetik - Hafıza | Ahlaki - Mantık | Ahlaki - Hafıza | Mantık - Ahlaki |
| O1 | 75% | 87.5% | 87.5% | 75% | 25% | 62.5% |
| O2 | 75% | 62.5% | 100% | 37.5% | 75% | 62.5% |
| P7 | 87.5% | 62.5% | 50% | 62.5% | 87.5% | 75% |
| P8 | 100% | 75% | 87.5% | 37.5% | 87.5% | 87.5% |
| AF3 | 62.5% | 62.5% | 62.5% | 62.5% | 75% | 75% |
| F7 | 62.5% | 75% | 75% | 62.5% | 75% | 75% |
| F3 | 75% | 62.5% | 87.5% | 62.5% | 100% | 75% |
| FC5 | 75% | 75% | 75% | 75% | 50% | 62.5% |
| T7 | 75% | 37.5% | 50% | 37.5% | 62.5% | 75% |
| T8 | 75% | 75% | 87.5% | 75% | 87.5% | 75% |
| FC6 | 75% | 87.5% | 100% | 25% | 25% | 75% |
| F4 | 62.5% | 75% | 62.5% | 75% | 62.5% | 62.5% |
| F8 | 75% | 75% | 75% | 50% | 75% | 50% |
| AF4 | 50% | 75% | 50% | 50% | 62.5% | 62.5% |

* Bu yöntem %7x\*9x arası verimli olmuştur.

****

**Tartışma**

* Geliştirdiğimiz veriye dayalı analizle her birey için önce farklı problemler-bilişsel fonksiyonlar için anlamlı olan elektrot pozisyonları belirlenmiştir. Sonrasında ise ilk kısımda elde ettiğimiz fonksiyon belirteci pozisyonlardan toplanan veriler, yeni bilişsel problemlerin çözümü sırasında ortaya çıkan aktivasyon işlenilerek, bu yeni bilişsel süreçte ne kadar rol aldığı tahmin edilmiştir.
* Analiz protokolü tamamen bireysel veriyle eğitilmiş olup veriye dayalıdır.
* Diğer sonuçlarla karşılaştır.
* Uzun vadede, ürettiğimiz sonuçları kullanıcıya geliştirilebilecek performans sergiledikleri durumlarda gerçek zamanlı olarak nörogeribildirim olarak sunup problem çözme süreçlerinde kullanıcının bilişsel süreçteki zihinsel stratejisini manipüle etmesine olanak tanınacaktır. Örnek vermek gerekirse, kısa vadeli kazanımlardan çok uzun vadeli kazanımların göz önünde bulundurulması gereken risk alma problemlerinde kişinin ödül mekanizması yerine aritmetik-olasılıksal hesaplara odaklanmasını teşvik eden bir sistem geliştirmesini amaçlıyoruz.

**Frekans ve bilişsel fonksiyon ilişkisi**

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**NFB for improving performance:** [**https://www.sciencedirect.com/science/article/pii/S0149763413002716#fig0030**](https://www.sciencedirect.com/science/article/pii/S0149763413002716#fig0030)

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**Bilissel fonksiyon siniflandirmasi EEG kullanarak:**

[**https://ieeexplore.ieee.org/abstract/document/8524729**](https://ieeexplore.ieee.org/abstract/document/8524729)

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**[5]NFB MEG:** [**https://www.sciencedirect.com/science/article/abs/pii/S1053811914010064**](https://www.sciencedirect.com/science/article/abs/pii/S1053811914010064)

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**Distinguishing Cognitive Tasks by Machine Learning Algorithms Applied to Electroencephalogram Signals**

**by**

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**Engineering Project Report**

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**Distinguishing Cognitive Tasks by Machine Learning Algorithms Applied to Electroencephalogram Signals**

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ABSTRACT

DISTINGUISHINGCOGNITIVE TASKS BY MACHINE LEARNING ALGORITHMS APPLIED TO ELECTROENCEPHALOGRAM SIGNALS

Different problem solving processes create different amplitude and frequency signals in various parts of brain.The purpose of this project is to distinguish these problem solving processes through examining EEG signals of individuals by using machine learning algorithms and signal processing. In this project the inspected processes include; arithmetic, memory related, logical and moral related decision making processes. After selecting the right electrode locations for discriminatingtheseproblem solving processes, the participant’s performance is modified via Neurofeedback. This method attempts to guess the individual’s performance while they are answering questions using the four different types of problem solving skills mentioned above. The brain activity of the individual will be monitored through the entire process of problem solving. To be able to guess the performance of the individual, machine learning algorithms will be used; algorithm will be trained with various signals then these signals are compared with individual’s own EEG signals. The performance of the individuals will be controlled to make use of various decision making processes simultaneously.

ÖZET

ELEKTROENSEFALOGRAMSİNYALLERİNEUYGULANANMAKİNE ÖĞRENMESİ ALGORİTMALARIYLA BİLİŞSEL GÖREVLERİ AYIRT ETMEK

Farklı problem çözmesüreçleri, beyninçeşitliyerlerindefarklıgenliktevefrekanstasinyalleroluşturur.Bu projeninamacı, makineöğrenimi algoritmalarıvesinyalişlemekullanarakbireylerin EEG sinyalleriniinceleyerek,bu problem çözmesüreçleriniayırtetmektir.Bu projededenetlenensüreçler; aritmetik, hafızaileilgili, mantıksalveahlakiproblem çözmesüreçleridir.Problem çözmesüreçlerininfarklılıkları tanımladıktansonra, buproblemlericevaplarkenbireyinperformansınıtahminetmeyeçalışanbirduyusalgeribildirimuygulamageliştirilmeyeçalışılacaktır.Bireyinbeyinaktivitesi, tümproblem çözmesüreciboyuncaizlenecektir.Bireyinperformansınıtahminedebilmekiçinmakine öğrenimi algoritmalarıkullanılacaktır; Algoritmaçeşitlisinyallerleeğitilecek, dahasonrabusinyallerbireyinkendi EEG sinyalleriylekarşılaştırılacaktır.Bireylerin performansı, çeşitli karar verme süreçlerini aynı anda kullanmak için kontrol edilecektir.

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**LIST OF SYMBOLS / ABBREVIATIONS**

ICA Independent Component Analysis

PCA Principal Component Analysis

KNN K-Nearest Neighbor Algorithm

FFT Fast Fourier Transform

MATLAB Matrix Laboratory

# **1.** **INTRODUCTION**

*Homo sapiens’* brain, against all the improvements in science and technology, still remains one of the greatest mysteries, waiting to be understood. This is mainly, due to the general complexity of the mental processes and neural activities. The brain, when observed from a greater perspective, handles multiple tasks ranging from regulating the blood pressure to solving acomplex integral, simultaneously. These various activities, handled at the same time, create a need for *reductionism*, a method that is applied in many biological subjects due to the dense analysis and information processing required in biological studies. Reductionism can simplybe expressed as, reducing the complex systems to simpler and smaller systems that eases the observation process [1].For this reason, in order to further understand the cognitive processes, it is necessary to reduce the observation space. Thus, it is required to locate the neural regions that specifically handle a certain task.This project focuses solving the problem of enlightening these regions.

Figure 1.1 Parts of the Brain [2]

As it can be seen from Figure 1.1, the brain is quite busy, managing diverse operations. While some portion of these processes’ region of management is explored, the details of problem solving is still in darkness.

Before starting the analysis of the experiment, it is necessary to understand cognitive processes and the general problem solving process since it is not a topic which is commonly explored in computer science.

## **1.1.** **Cognitive Processes**

In order to define cognitive processes in brain, the term of attention must be explored. According to Kahneman’s Capacity Model of Attention, attention can be defined as a resource that is used bybrain. Resources in brainareenergy and mental efforts that are used to complete a job. Just like computers having a limited amount of resources to distribute among the processes that they need to complete, the brain has a limited amount of attention as a resource.Consider the following figure that is Kahneman’s model [3].

Figure 1.2 Kahneman’s Capacity Model of Attention[4]

Observing the figure, the box at the top of the figure represents the amount of attention available. Amount of attention available is not constant, based on the physiological attributes called arousals, such as heart-beat rate due to adrenaline, amount of attention that can be distributed among the jobs can be increased and decreased. The relation between the arousal and attention is explored in Yerkes-Dodson law [5];

Figure 1.3 Yerkes-Dodson Law [6]

Based on this graph, amount of attention available is at its optimum when the arousal is at middle levels.

Continuing with Figure 1.2, miscellaneous determinants are the parameters that mechanically provide the brain with energy. These parameters include sleeping and eating since they add to the energy that is stored in the brain. Miscellaneous manifestations are actions which reduce the amount of attention that can be provided. These actions can be considered as twitches, such as finger tapping which decreases the extensive attention.

The ellipse in the middle of the figure is called the allocation policy. While this term is rather fancy, it is something that is accustomed to. Using the computer science analogy, allocation policy is basically a process scheduler. Allocation policy determines the amount of attention that is provided to a cognitive process. This policy is effected by two parameters; enduring dispositions and momentary intentions. Enduring dispositions generally are the events outside the brain that happens in an instant, which draws attention. Evolutionary, the brain reduces the attention that is given to the current cognitive processes to determine whether the event that newly occurred, poses a threat for itself. As for momentary intentions, the conscious self can momentarily change the attention given to a job to attend to another job. With these out of the way, cognitive processes can now be explained; based on the information received from the environment and the resources allowed from the brain, cognitive processes are the operations that try to resolve a task in brain, simultaneously. These processes also receive information from past experiences and senses [7].

With that said, the general study of brain is called neuroscience and with the definition of cognitive processes that has been made, the attempt to explain these processes by analyzing the physiological infrastructure in brain is called cognitive neuroscience [6]. Cognitive neuroscience tries to explain the relation between the mind (which can be referred as the “software”) and the brain as its physical structure (which also can be referred as the “hardware”).With the new technologies, the “hardware” at work can be observed with gradually getting better resolutions using the equipment such as computerized axial tomography (CAT), magnetic resonance imaging (MRI) and electroencephalogram (EEG) [7].

## **1.2.** **Problem Solving Process**

Based on the definition that is done by Hayes, problem solving is the reaching from a given situation to a desired situation by employing some actions [8]. While many explanation are done to explain the process of problem solving, in this project the characteristic that are determined by Anderson are used due to its close relationship with artificial intelligence. Anderson’s approach is based on setting sub-goals along the way to the ultimate goal. Trying to reach to the ultimate goal, a number of different pathways are tested. There are four characteristics in this problem solving process which are;

*1. GoalDirectedness:* Problem solving process directly focuses on the solution and tries to reach the wanted state.

*2. Sequence of Operations*: While problem solving process tries to reach the desired state directly, to reach to this state, the brain does a number of sequential operations. Using the computer science analogy, this process can be considered as the processor doing a number of machine commands in order to execute a program which can be considered as the desired state.

*3. Cognitive Operations:* These are the operations that when applied to a state, transforms this current state into another with the assistance of some input parameters.This is the point that this project tries to enlighten, what parameters are used to what degree?

*4. The Setting of Sub-goals:* Each cognitive operation or step, results in a sub-goal which is an intermediate goal along the way to the ultimate goal.

Based on these four definitions, the problem solving processes can be visualized as a tree structure where each transition is a result of a cognitive operation [9].

Figure 1.4 Stages of Problem Solving Process [10]

Each branch that is multiple represents a choice and not all the branches reach to the desired state. For this purpose, the steps taken are needed to be analyzed and treated with care. With problem solving process explained with its general boundaries, introduction is concluded.

# **2.** **BACKGROUND**

## **2.1.** **Previous works**

Most of the signal processing protocolfollowedin this project are based on the following publications;

· Neurofeedback training of the upper alpha frequency band in EEG improves cognitive performance by BenediktZoefel, René J. Huster, and Christoph S. Herrmann.

*In this study, the individually determined upper alpha frequency band in EEG was investigated as a Neurofeedback parameter. Fourteen subjects were trained on five sessions within 1 week by means of feedback dependent on the current upper alpha amplitude. On the first and fifth session, cognitive ability was tested by a mental rotation test.* As a *result, eleven of the fourteen subjects showed significant training success. Individually determined upper alpha was increased independently of other frequency bands*

· Investigating critical frequency bands and channels for EEG-based emotion recognition with deep neural networks by Wei-Long Zheng, Bao-Liang Lu.

*To investigate critical frequency bands and channels, this paper introduces deep belief networks (DBNs) to constructing EEG-based emotion recognition models for three emotions: positive, neutral and negative. EEG dataset acquired from 15 subjects is developed. Each subject performs the experiments twice at the interval of a few days. DBNs are trained with differential entropy features extracted from multichannel EEG data. The weights of the trained DBNs are examined and the critical frequency bands and channels are investigated.*

# **3.** **ANALYSIS**

The experiment can be analyzed in four different parts; data collection which includes experiment to gather data from the subjects, pre-processing which includes the cleaning of the gathered data from unwanted noises, signal classification which includes the extraction of meaning from the cleaned data and finally the Neurofeedback which includes informing the user about their cognitive processes and improving the performance of user.

## **3.1.** **Data Collection**

In order to locate the area of processing and distinguish the cognitive processes, data must be collectedfrom subjects' brain. For this purpose, electroencephalogram can be used. Electroencephalogram (also known as EEG), is a gadget that is used to record the electrical activity of brain based on the voltage fluctuations. These voltage fluctuations are a result of the communication between neurons. Since neurons use electrical current as the communication agent, a potential difference between two locations is created which can be observed via the electrodes of the EEG. In this project, for EEG, EmotivEpoc+ 14 is used which can be seen in the following figure;

Figure 3.1 EmotivEpoc+ 14 EEG [11]

Epoc+ 14, has 14 electrodes and uses soaked pads for transmission of signals to EEG. It can detect signals up to 8400μV using sequential sampling [11]. The 14 electrodes that EEG has are as follows;

Figure 3.2 Electrode Locations for Epoc+ 14 [11]

As it can be seen from the Figure 3.2, there are various electrodes recording data from various parts of the brain's lobes. For example, O1 and O2 records data from the left and right side of the occipital lobe respectively. Using the versatility of these electrodes and their recording parts of the brain, the signals can be located to a certain degree of accuracy. Based on the Figure 1.1, most of the problem solving process is done in the frontal lobe which means that most of the valuable data will be received from the electrodes AF3, AF4, F3, F4, F7, F8, FC5 and finally FC6.

However, it is important to note that, since EEG gathers data from the surface of the head, the neural activity that is located in inner parts of the brain cannot be recorded. If such neurons are needed to be observed, Magnetic Resonance (MR) should be used. It should also be noted that, EEG’s reading will be heavily distorted by hair and in order to read data accurately, a solution that is highly rich in an electrolyte substance should be used to damp the electrodes.

With that said, following figure denotes how EEG should be located in subject's head;

Figure 3.3 EEG Location on Subject's Head [11]

## **3.2.** **Experiment and Experiment Environment**

Due to sensitive nature of the neurons, any kind of external parameter is going to disrupt the data readings.For this reason, the experiment should be done in an environment that does not contain any other light sources other than the experiment itself. The experiment environment must be quiet since any sound sources can disturb neural activities thus can cause errors during readings. Also, there should not be any computer present in the environmentsince computers can disrupt the EEG readings due to their magnetic field, again with the exception of the computer that the reading is done. With that said, the subject should not move, or speak and should stay concentrated whilst the experiment is being conducted. This is because of the neural activity; any muscle movement, any noise or light will create a signal response in some certain group of neurons, since these signals travel to the nearby neurons like waves in water, the readings will contain artifact from these operations which is unwanted. Especially the muscle movements and speech effects the reading done on problem solving process since the neurons that focus on problem solving processesare located at frontal lobe.

In the experiment, the subject is asked to answer different types of questions. These questions are categorized as memory questions, moral questions, arithmetic questions and finally logical questions. While the answers do not matter, it is necessary that subject spends time and effort solving these questions in order to gather more accurate data. While, the questions are answered, time should be calculated and if an external obstruction occurs, the data in that time and question should be discarded due to distortion in signals.

Also the electrodes should be properly placed in the subjects head and any hair that obstructs the contact between the skin and the hair should be removed.

## **3.3.** **Experiment Process**

The experiment has three parts. For the first part, a set of 20 questions are asked to the subject. As mentioned previously, there are four subjects; memory questions, moral questions, arithmetic questions and logical questions with each having 5 questions in total. These questions are asked to the subject in random fashion. This is done to subvert the expectations of the subject which results in more accurate signals. There is no time limit to answer these questions.The second part includes the same ratio of questions and subjects. For the third and final part, 3 questions that combine these subjects are asked by this way the subject can be told about which process that he/she uses the most.Also, the questions in the experiment should also be relatively simple, short and the subject’s native language should be used to ask the questions in order to minimize the artifacts from translation and reading. With that said, while the signal are being recorded, the processes that are done in the computer background should be minimized due to recording being a costly process.

## **3.4.** **Pre-Processing**

In order to extract accurate and precise information, a processing is needed to be applied to the data gathered in order to get rid of artifacts in the data and shape the signal into the wanted composition.For this purpose, initially, *Independent Component Analysis*(ICA) is applied to the signal. Since the eye muscles create a noise that heavily affect the neural activity in brain, the traces of these signals must be eliminated for accurate processing. ICA serves the purpose quite well, it separates the signal into its components from which the eye blink signals can be found, selected and removed.

With that done, *de-trending* is applied to the signal. With de-trending, extreme values in the data can be removed based on the linearity. De-trending also normalizes the signal at origin. Consider the following figure for the effect of the de-trending;

Figure 3.4 De-trending Operation on a Signal [12]

After this, a *bandpass filter* is applied to the signal to further cleanse the signal from noisecaused from the high frequencies and the low frequencies.

Then, *Fast-Fourier Transform* (FFT) is applied to the signal so that the signal can be inspected in frequency domain rather than the time domain. By this way, signal can be categorized by the general signal type categories that is used in the cognitive science. Following figures denote the FFT process and the signal types that are used;

Figure 3.5 Fast Fourier Transform on a Signal [13]

As it can be seen from the figure, the time domain has been changed to frequency domain. There are some noises in the signal that can be seen from the result of the FFT, these are the extreme points on the right-hand side graph.

Figure 3.6 EEG Signal Bands [14]

As it can be observed from the Figure 3.6, there are five types of bands in EEG signals which are gamma, beta, alpha, theta and delta bands. More active neurons have signals similar to gamma band while the more idle neurons have signal that are alike to delta band.

In the literature, alpha-band (8–13 Hz) has been found relevant totheattentional load and inhibition of brain activity[15].The beta-band (13–30 Hz) has been foundrelevant to top-down attention control and maintainingthe ongoing function[16].The gamma-band (> 30 Hz) activation has been associated with conscious cognitive functions such as processing sensory information, attention, and executive control of functions [16].

## **3.5.** **Signal Classification**

With signal cleansedand turned into frequency domain, now the signal can be categorized and examined for features. For this purpose, Principal Component Analysis (PCA) is used. Based on the electrode from which the data is received and by the question type, the specific data for that question type is fed to the PCA. By this way, the differences of the signals can be found. The resultingdata which are made of the coordinates of the principal components, is then supplied to K-Nearest Neighbor (KNN) machine learning algorithm so that the cognitive process can be categorized based on the accuracy of classifications.

## **3.6.** **Neurofeedback**

Based on the classification done in the previous part, the sensor locations and task categories that revealed the best classification accuracies for determining which task the subject is dealing with will be used in a second task.In this part of the experiment, thesubject will be guided based on the brain activity relevanttothe cognitive process that they use at the moment. This means that, the cognitive process that is used for the problem solving process by the subject will be indicatedto the subject indirectly – through a feedback bar –and if required, the subject will be asked to change their strategy for problem solving.

## **3.7.** **State Diagram**

With all parts of the experiment described,a state diagram, which sums up the entire experiment process is as follows;

Figure 3.7 State Diagram of the Experiment

Obstructions in Figure 3.7 refer to the coughs, sneezes, movements, loud noises or lights which are explained previously, these events disturb the data readings thus the data reading for that question should be discarded.

Before beginning the implementation another state diagram that explains the pre-processing and Neurofeedback operation is necessary to be explored.

Figure 3.8 More Detailed Neurofeedback & Pre-processing State Diagram

# **4.** **DESIGN AND IMPLEMENTATION**

As done in the analysis chapter, the project is also viewed in four different parts in design and implementation chapter excluding feedback since it is same as the experiment.

## **4.1.** **Experiment Design**

The experiment is designed in MATLAB using the psychtoolbox.Combining the first two parts of the experiment, there are 10 questions of each category. The questions are asked in Turkish in order to avoid the overhead caused by translating the questions to the native language. With that said, the questions are preferably kept short due to the overhead caused by reading process. The subject can answer the questions using the keyboard whenever they choose to; there is no time limit. Questions used in this experiment are as follows;

*Memory Questions,* as the name would suggest, these questions are aimed to cause a remembrance of a memory for the subject. There are long term memory and short term memory questions in the experiment.

*Moral Questions,* these questions are based on creating a moral dilemma in subject’s mind. These questions tend to be longer than the rest of the questions due to their nature; the situation must be explained to the subject before they can make a decision.

*Logical Questions,* these questions are based on logic and linguistic. All the questions are the same with answer options being different; given a set of letters, create a meaningful word.

*Arithmetic Questions,* these questions are based on making the user solve a rather simple mathematical expression.

As mentioned previously, these questions are asked in random order. If otherwise is done, the subject might get used the cognitive process which can lead to alterations in brain signals. With that said, the contents of these question will be inspected completely in chapter 5.

Following figures are the examples taken from the experiment process for better understanding of the experiment;

Figure 4.1 Welcoming Page of the Experiment

Figure 4.2 Example Memory Question of the Experiment

Figure 4.3 Example Logical Question of the Experiment

Figure 4.4 Example Arithmetic Question of the Experiment

Figure 4.5 Example Moral Question of the Experiment

It is also important to start a timer as the experiment starts since the time intervals are going to be used in signal processing. For this reason, MATLAB function tic and toc is used in the experiment. With that said, it is also necessary to keep the track of the question types since they are asked in random. For this reason, a hash table that keeps the questions is implemented. Also, the subject should not be allowed to press any key but the answers keys in order to record the answer. Addition to that, the interface that the questions are asked should be rather simple so that it does not cause any distractions and the tasks should be explained to the user before the experiments starts in order to avoid confusion.

Recording of data is done with EPOC+’s Python interface. Before experiment starts, a file used to signal the python program, so that the data recording can start at the same time the timer and the answering process begins.

With that said, any external effects such as a cough, or sound should be noted during the experiment, and the data of these processes should be discarded for better results.

## **4.2.** **Pre-Processing Design**

For all pre-processing processes, MATLAB is used. In this section, these processes will be inspected in detail. As an overview of the pre-processing the operation done are as follows; de-trending, bandpass filtering, independent component analysis and finally fast Fourier transform in order.

Let us start with the ICA since de-trending and bandpass filtering are mostly done to supply cleaner signals to ICA.ICA is mainly used to remove eye blink artifacts from the signal. Also, ICA detects many other noises that is existent in the signal that can be removed from the data. Since there are 14 channels in the EEG, a total of 14 independent components can be found, from which the unwanted data is eliminated. This remove operation is done based on the eye blink data examples found in the essay that is denoted in the previous works chapter. The ICA used in the experiment is an additional package for MATLAB.

In some of the cases, eye blink can be found as amixture with other signals. In this case, the signal that contains the eye blink mixture should be removed because eye blink effects the remaining processes and feature extraction the most.

With that said, de-trending process can be explored now. Consider for example a rawsignalthat is recorded from O1 and O2 electrodes;

Figure 4.6 Signal Received from O1 and O2 Electrodes

Applying de-trending to these signals using the de-trend built-in function in MATLAB, the following signals are obtained;

Figure 4.7 De-trended Signal from O1 and O2 Electrodes

As it can be seen from the Figure 4.7, applying de-trending to the signal reduces the distance of extreme points to the base of the signal by fitting the signal around a trend line which is shown in analysis chapter. With that said, the reduction of extreme points are relatively small however the signal is fit to the horizontal line meaning that the detrending operation was successful. This trend line is determined by the MATLAB function detrend. When a matrix of data is supplied to this function, the trend line is created automatically. By default, the order of the line is first order, but this order can be changed to create more precise trend lines.

Afterthe detrending process, band-pass filter was applied on the signals. Consider for example the data gathered from F8 and AF4 electrodes;

Figure 4.8 Signal Received from F8 and AF4 Electrodes

When this signal is band-pass filtered by using the bandpass filter function in MATLAB, the following signal is obtained. Note that while the original signal is shown in figure above. In the figure shown below, the band-pass filter is applied to the de-trended signal not the original one.

Figure 4.9 Band-passed Signal from F8 and AF4 Electrodes

Band-pass signal eliminates high frequency and low frequency signals which are mostly noises in the brain signal. However, MATLAB uses a complex band-pass filter which needs further explanation.There are 8 parameters that fdesign library’s band-pass filter function accepts which are N (order of filter) and Fstop1, Fstop2, Fpass1, Fpass2, Astop1, Astop2 and Apass. While these parameter sound complex, the following figure explains their purposes crystal clear.

Figure 4.10 Parameters Used in Bandpass Filtering [17]

As it can be seen from the Figure 4.10, Fstop values denote the frequencies that are going to be filtered out while the Fpass values denote the frequencies that will be kept. Same reasoning applies for A values too, only difference is A values denote the amplitude. Note that the graph is in frequency domain.

Using all the de-trended and band-passed signals, independent component analysis can be done to extract the most important 14 component from the signal. Following are the 14 independent components that are extracted from the signal recorded using the 14 electrodes. Note that, not all the original signal samples are shown here. With that said, the remove operation is based on the essay that is denoted in previous work chapter.

Figure 4.11 Independent Components 1 and 2

Figure 4.12 Independent Components 3 and 4

Figure 4.13 Independent Components 5 and 6

Figure 4.14 Independent Components 7 and 8

Figure 4.15 Independent Components 9 and 10

Figure 4.16 Independent Components 11 and 12

Figure 4.17 Independent Components 13 and 14

The signal that should be filtered out are the signals which have extreme points and the ones which has too much deviation.The components 9, 10, 11, 12, 13 and 14 are alike the brain signal expected. Thus, in this case, the removed components are 1, 2, 3, 4, 5, 6, 7 and 8 due to containing too much extreme points. After the noise components are removed, the signals obtained are as follows. Note that not all the signal are shown here.

Figure 4.18 Signals After ICA for O1 and O2 Electrodes

Figure 4.19 Signals After ICA for F8 and AF4 Electrodes

Since the signals are now cleaned, fast Fourier transform can be applied to the signal to change the signal into frequency domain from time domain. The following signal are obtained as the result of FFT, applied to the O1 and F8 electrodes.

Figure 4.20 The O1 Signal After FFT is Applied

Figure 4.21 The F8 Signal After FFT is Applied

Now, these signal can be supplied to the principal component analysis, which returns a graph based on the similarity of the signals. Points of this graph can be supplied to a machine learning algorithm for classification.

## **4.3.** **Signal Classification Design**

For every electrode and question type, a PCA is applied to the signal in order to compare the distinction of signals. The resulting graph contains data points based on the number of questions asked for each type with x axis being the time and the y axis being amplitude. These data points will be supplied to KNN to be classified. Consider for example for AF3 these are the result of PCA;

Figure 4.22 Arithmetic vs. Moral and Arithmetic vs Logical Graphs Obtained from PCA

Figure 4.23 Arithmetic vs. Memory and Moral vs Logical Graphs Obtained from PCA

Figure 4.24 Moral vs. Memory and Logical vs Memory Graphs Obtained from PCA

## **4.4.** **Neurofeedback Task**

Once the data is obtained from the first and the second part of the experiment, this data can be used to increase the performance of the subject while subject is answering composite question which are the question that include more than one theme of question. Consider for example, the following question which combines the arithmetic and moral parameters in one question;

Figure 4.25 Example Composite Question from the Experiment

Figure 4.26 The Feedback Bar Indicates How Well Two Joint Cognitive Functions are Involved in Decision Making, Calculated By PCA Classification Accuracy

# **5.TEST AND RESULTS**

## **5.1.** **Questions Used in the Experiment**

The questions used in the experiment are as follows, note that the first 5 questions are asked in the first part of the experiment while the last 5 is asked in the second part of the experiment.

Table 5.1 Memory Questions Used in the Experiment

|  |
| --- |
| What did you eat at dinner yesterday? |
| Who did you talk to on the phone lastly? |
| What was the dream that affected you the most? |
| What is the most recent movie you watched? |
| What did you talk about with your best friend lastly? |
| What was the first question you answered in the last experiment? |
| What was the name of the book you read lastly? |
| What was the memory that affected you the most? |
| Where did you have your last holiday? |
| What was the last subject you studied? |

Table 5.2 Moral Questions Used in the Experiment

|  |
| --- |
| You're in a bank. A man robs the bank and says he will donate the money to the orphanage and the poor. What would you do? |
| You're a doctor of five patients waiting organ transplants. In spite of all, the organs searched could not be found. You have a sixth patient who is dying. If theydie, their organs will save other five patients. You have got a cure to heal sixth patient completely. What would you do? |
| You are in a company. A person will be recruited. Two people are applying. One is unemployed for a long time, has no work experience, inadequate in the field, but is yourclose friend who needs a job, the other is an experienced, professional person yet someone you do not know. What would you do? |
| You are in gang. You have committed a crime and you have been caught with another member. In two separate query rooms, you are being interrogated. You can accept remission and confess the crime or you can remain silent but in this case other member can blame you. What would you do? |
| You are a teacher. A good and successful student of yours who is a candidate for graduation is getting sick and copies his last assignment from another student. You noticethis. If you report this situation, your student will be penalized. What do you do? |
| You are in a company. You have done a project as a group and this project achieveda prize, but only you know the prize. You can save the prize money for yourself or share the prize money. What would you do? |
| You're in a company. One of the companies’ workers will be dismissed. Either you are going to leave the company, or you will have to dismiss a close friend. What would you do? |
| If you could save a person that you know or thousands of people that you do not know, what would you do? |
| Which one would you choose, living up to 105 years old or dying at 70 years old? |
| Which one would you choose, to know about a topic completely or know about all topics a little? |

Table 5.3 Arithmetic Questions Used in the Experiment

|  |
| --- |
| What is the result of 102/3? |
| What is the result of 67x3? |
| What is the result of 132/11? |
| What is the result of 98/7? |
| What is the result of 76\*4? |
| What is the result of 105/7? |
| What is the result of 73x3? |
| What is the result of 143/13? |
| What is the result of 108/9? |
| What is the result of 56\*4? |

## **5.2.** **Accuracy Result From KNN Algorithm**

Since there are 14 electrodes and 6 different question combinations, a total of 84 accuracy values will be calculated. In current data set there are 40 data points to be classified, these data set is separated in to two sets; training set which has 32 points and test set which contains eight points. Based on the accuracy rate, it can be determined whether the electrode can be used to distinguish the two problem types explored.

Table 5.4 Accuracy Results Obtained From KNN

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Arithmetic vs. Moral | Arithmetic vs. Logical | Arithmetic vs. Memory | Moral vs. Logical | Moral vs. Memory | Logical vs. Memory |
| O1 | 75% | 87.5% | 87.5% | 75% | 25% | 62.5% |
| O2 | 75% | 62.5% | 100% | 37.5% | 75% | 62.5% |
| P7 | 87.5% | 62.5% | 50% | 62.5% | 87.5% | 75% |
| P8 | 100% | 75% | 87.5% | 37.5% | 87.5% | 87.5% |
| AF3 | 62.5% | 62.5% | 62.5% | 62.5% | 75% | 75% |
| F7 | 62.5% | 75% | 75% | 62.5% | 75% | 75% |
| F3 | 75% | 62.5% | 87.5% | 62.5% | 100% | 75% |
| FC5 | 75% | 75% | 75% | 75% | 50% | 62.5% |
| T7 | 75% | 37.5% | 50% | 37.5% | 62.5% | 75% |
| T8 | 75% | 75% | 87.5% | 75% | 87.5% | 75% |
| FC6 | 75% | 87.5% | 100% | 25% | 25% | 75% |
| F4 | 62.5% | 75% | 62.5% | 75% | 62.5% | 62.5% |
| F8 | 75% | 75% | 75% | 50% | 75% | 50% |
| AF4 | 50% | 75% | 50% | 50% | 62.5% | 62.5% |

Looking at the Table 5.4, it is observed that some of the electrodes are not used in order to determine the performance. A question arises from this observation, whether the unused electrodes can be removed? As much as this removal operation would increase the performance processing and real time response of the Neurofeedback, it cannot be done. The values seen in this table depend on the individual. For example, while FC6 has a high rating for distinguishing in between arithmetic and moral questions for the subject, another subject may show this pattern in electrode AF4. Thus, it is necessary to check all the electrodes for accuracy for every subject.

# **6.CONCLUSION**

Here we demonstrated a neuroffeedback tool that discriminates the brain states from specific regions and uses this outcome to guide subjects to control the cognitive abilities they perform while making decisions.

Firstly, we asked subjects to answer different types of questions that require them to perform several cognitive tasks. The sensors that best discriminate two of these different types of questions were selected. The accuracy scores ranged between 75% and 100% (Table 5.4) while picking a sensor. This helped us to perform dimensionality reduction and therefore enabled faster processing in the neurofeedback part of the experiment. In the second part, data from these selected sensors were used to decode which cognitive skills the subjects use while evaluating/solving a joint task. Theory of attentional processing states that using several cognitive processes help make better decisions. According to this hypothesis, we gave feedback to users based on how well they used both types of cognitive skills while solving a joint task (arithmetic-moral, verbal-moral, etc.).

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