THE JOURNAL OF COGNITIVE SYSTEMS

an international, peer-reviewed
indexed, and open-access periodical

www.dergipark.gov.tr/jcs

VOLUME 04
NUMBER 02
YEAR 2019
ISSN 2548-0650

THE JOURNAL OF
COGNITIVE SYSTEMS

An international, peer-reviewed,
indexed, and open-access periodical

ISSN 2548-0650

AIM & SCOPE

The Journal publishes original papers in the field of artificial intelligence, biomedical, quantum information, big data analysis and statistical areas, which are related with cognitive science and engineering, as well as the applications of the cognitive studies in social areas. Letter to the editor is also encouraged.

THE JOURNAL OF
COGNITIVE SYSTEMS

CONTACT

Prof. Dr. Özer Ciftcioglu
Editor-in-Chief of The Journal of Cognitive Systems
Delft University of Technology, The Netherlands
Istanbul Technical University, Istanbul, Turkey

E-MAIL

cognitive@itu.edu.tr

WEB PAGE

www.cognitive.itu.edu.tr

URL

www.dergipark.gov.tr/jcs

THE JOURNAL OF
COGNITIVE SYSTEMS

VOLUME 04, NUMBER 02

DECEMBER 2019

CONTENTS

THE EFFECT OF THE ENVIRONMENT ON BRAIN ACTIVITY DURING PROBLEM SOLVING

S.G. Eraldemir, M. Arslan, E. Yıldırım, and A.F. Koc

Abstract**—**In all functions of the brain, electrical signals called volumetric conduction occur in nerve cells in the brain. The process of measuring and recording these electrical signals by means of sensors placed in certain areas on the scalp is called electroencephalography (EEG). EEG signals occur in body movements, sleep and wakefulness, and in all kinds of processes in the brain, including cognitive processes. In this study, we investigate the effect of city noise and popular music environments while solving questions with different levels of difficulty (simple and hard) employing the EEG signals in Cognitive Tasks Database in Different Environments. Features are extracted from the EEG data, collected from 17 undergraduate and postgraduate students while solving simple and hard questions, by means of Continuous Wavelet Transform. EEG signals recorded while solving simple and hard questions, in city noise and popular music environments are classified with average accuracies of 90.10% and 93.92%, respectively using Bayesian Networks. Results show that, EEG data collected in two different environments, noise and favorite music, while solving problems can be classified with high accuracy and distinction can be made with higher success for difficult questions.

Keywords**—***EEG, Cognitive Tasks, Classification, City noise and Popular music environments*

1. INTRODUCTION

THE process of recording electrical signals produced in the brain is called EEG. The frequency range of the EEG signals varies between 0.5-100 Hz, and the amplitude is about 1-100µV. EEG signals are used in the diagnosis and treatment of various diseases in addition to providing information about all kinds of processes that occur in the brain by means of EEG signals [1,2,3,4,5].

Music is an educational activity. The lifestyle and view of life of individuals can change with the help of music [6]. Using music in education enables the creation of a positive emotional environment in learning due to the relationship between music and emotions. It is also known that listening to some music contributes to the individual's concentration skills [7]. The level of electrical energy in the brain nerve cells affects the individual's concentration and fatigue impact scale. It has been stated that, concentration decreases and fatigue occurs as the energy of the individual decreases. Therefore, high frequency music between 5000 and 8000 Hz should be given as stimulus to the individual in order to increase the energy in brain cells [8].

It is accepted that noise has psychological and physiological negative effects on people. There are many sources of noise in cities. One of the most important of these sources is the traffic noise in the city centers. Many studies have shown that traffic sound can be accepted as noise pollution [9, 10, 11]. There are three main factors affecting road traffic noise. These are the noise caused by vehicles, the noise caused by the interaction of vehicles with the road and the environment, and the noise caused by the driver. Traffic noise on the road is composed of components such as motor noise, brake sounds and the sounds of the wheels on the road. Noise originated by the driver is mostly caused by improper use of vehicles. The most important factors in driver-induced noise are the sounds generated by the use of horns and removal of parts that provide sound insulation in vehicles [12].

In this study, we conducted a study on whether individuals were affected by their environment during a cognitive task. EEG signals recorded while subjects are solving the questions consisting of numerical and visual logic questions were compared each other on traffic noise and favorite music environments.

2. MATERIAL AND METHOD

The main steps used in the study is summarized in Figure 1.

Fig.1. The basic steps of the experimental study

2.1. EEG Recordings

EEG signals in Cognitive Tasks Database in Different Environments are used in this study. EEG data in this dataset are collected from a total of 17 healthy and all-male participants who are studying undergraduate and postgraduate on a voluntary basis in this study. The participants are asked a total of 10 questions consisting of numerical, visual and verbal questions with different degrees of difficulty in their favorite music and traffic noise environments. These questions are approved by the International Cognitive Ability Resource (ICAR) project [13], jointly conducted by Germany, the United States and the United Kingdom. ICAR is a project that researchers are allowed to access on the internet. This project provides a wider assessment of cognitive abilities in psychology and other social sciences and aims to facilitate neuropsychological assessment in medical research. In this study, problems were translated to Turkish, by permission,

Server Göksel ERALDEMİR, Iskenderun Technical University, HATAY, Turkey, (sgoksel.eraldemir@iste.edu.tr)

Mustafa Turan Arslan, Mustafa Kemal University, Hatay, Turkey, (e-mail: mtarslan@mku.edu.tr)

Esen YILDIRIM, Adana Alparslan Turkes Science and Technology University, Adana, Turkey, (e-mail: eyildirim@atu.edu.tr)

Ayşe Filiz Koç, Çukurova University, Adana, Turkey (e-mail: filizkoc@cu.edu.tr)

Manuscript received Sep. 17, 2019; accepted Nov. 18, 2019.
Digital Object Identifier:

since all the subjects are native Turkish speakers. Samples for each problem type used in the experimental setup during EEG recording are shown in Figure 2-4.

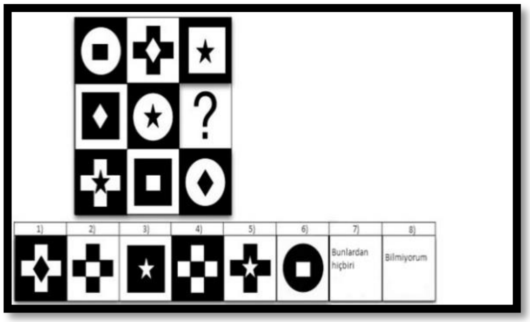


Fig. 2. A visual question

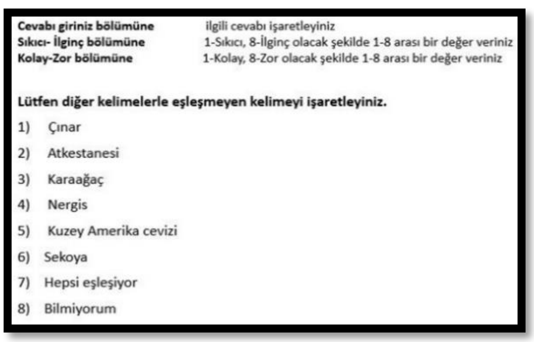
Cevabı giriniz bölümüne ilgili cevabı işaretleyiniz
Sıkıcı- İlginç bölümüne 1-Sıkıcı, 8-İlginç olacak şekilde 1-8 arası bir değer veriniz
Kolay-Zor bölümüne 1-Kolay, 8-Zor olacak şekilde 1-8 arası bir değer veriniz

Aşağıdaki sayı serisinde, sırada hangi sayı vardır?

4, 7, 11, 18, 29, ...

1) 37
2) 39
3) 46
4) 47
5) 49
6) 55
7) Bunlardan hiçbiri
8) Bilmiyorum

Fig. 3. A numerical question



Cevabı giriniz bölümüne ilgili cevabı işaretleyiniz
Sıkıcı- İlginç bölümüne 1-Sıkıcı, 8-İlginç olacak şekilde 1-8 arası bir değer veriniz
Kolay-Zor bölümüne 1-Kolay, 8-Zor olacak şekilde 1-8 arası bir değer veriniz

Lütfen diğer kelimelerle eşleşmeyen kelimeyi işaretleyiniz.

1) Çınar
2) Atkestanesi
3) Karaağaç
4) Nergis
5) Kuzey Amerika cevizi
6) Sekoya
7) Hepsi eşleşiyor
8) Bilmiyorum

Fig. 4. A verbal question

EEG data is collected with 14-channel, wireless, high quality Emotive EPOC+ which can automatically remove network noise. EEG device are demonstrated in Figure 5.

Fig. 5. Emotiv EPOC+ device

The EEG device has 14 electrodes consisting of AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. The sampling frequency is 128 Hz.The electrodes are placed on the scalp in accordance with the internationally recognized 10-20 system. An example image collected from volunteers during EEG recording is shown in Figure 6. Details of the database can be found in [14].

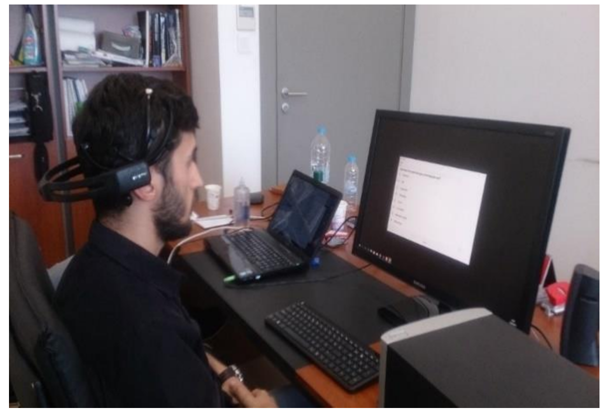


Fig. 6. The position of the device on the scalp and test environment

TABLE I
EXPERIMENTAL SETUP

Rest (10 sec)	Stimulus (Duration changes with the difficulty of the question)	Marking (20 sec)	Rest Duration (10 sec)	………	Stimulus (Duration changes with the difficulty of the question)	Marking (20 sec)	Rest (10 sec)

2.2. Pre-Processing

50 Hz network noise is automatically cleaned by the device during recording EEG signal. After the recordings, signals are bandpass-filtered between 0.2 and 45 Hz.

2.3. Feature Extraction

Continuous Wavelet Transform (CWT) is calculated as the convolution of the signal by an analysis function, similar to Fourier Transform (FT).However, the trigonometric basic sine analysis functions in FD have been replaced by the wavelet function, called mother wavelet, in CWT. The mother wavelet is a function with different frequency contents as opposed to the sine (or complex exponential) function with constant frequency content. Time information is obtained by shifting the mother wavelet along the signal. Frequency information is captured by means of opening and contraction of wavelet. The CWT is defined as follows [15].

$$CWT_X^{\psi} = W_X(\tau, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{+\infty} X(t).\psi * \left(\frac{t-\tau}{s}\right) \quad (1)$$

CWT_X^{ψ} depends on τ and scale parameter s. $\psi(t)$ is a transformation function and it is called fundamental wavelet. Other window functions used for transformation are derived from this wavelet. The energy of the signal is normalized at each scale by dividing the wavelet coefficients by $1/\sqrt{s}$. Thus, the same energy is obtained at each scale.CWT is used for feature extraction in this experimental study. By this method, energy values are obtained for each channel in the time-frequency domain. The total energies in the theta (3-7 Hz), alpha (8-12 Hz), beta (13-29 Hz) and gamma (30-45 Hz) bands and the ratio of these energies to total energy are used as features. Features are extracted from 1 second segments with 50% overlapping.

2.4. Classification

Bayesian Network serves to classify EEG data in this study. This method works based on Bayesian Theorem. Bayesian network is an algorithm which is used for analysis of high-dimensional data. The algorithm is efficiently and reliably formed by the development of existing methods to solve hard questions [13].

3. RESULTS

Table 1 shows the effect of the environments (city noise and popular music) on EEG signals recorded while solving simple questions for each participant.

TABLE II
THE CLASSIFICATION RESULTS OF EEG SIGNALS RECORDED WHILE SOLVING SIMPLE QUESTIONS IN CITY NOISE AND POPULAR MUSIC ENVIRONMENTS FOR ALL PARTICIPANTS

No of Participant	Accuracy	Precision
1	90.17	90.24
2	88.03	88.59
3	77.35	78.26
4	81.62	81.63
5	88.89	89.18
6	99.15	99.15
7	81.62	82.68
8	88.89	88.93
9	96.15	96.16
10	92.74	93.12
11	85.47	85.56
12	86.75	86.82
13	97.44	97.45
14	79.49	79.63
15	99.57	99.58
16	98.29	98.35
17	100	100
Average	**90.10**	**90.31**

Examining Table 1,17th participant has the highest classification success, with accuracy rate of 100%. On the other side, 3rd participant has the poorest accuracy, 77%. During the solution of simple questions, it is seen that city noise and popular music sounds make differences on the recorded EEG signals of the participants. Table 2 shows the results on EEG signals acquired when solving hard questions in above-mentioned environments.

As is seen from Table 2, environments can be distinguished from each other by an average accuracy of 93.92% when Bayesian Network algorithm is performed to EEG features extracted by continuous wavelet transform. Moreover, participant 7 has the worst classification result, with accuracy rate of 81.99% although participant 6 and participant 16 have the highest classification result with accuracy rate of 100%.

TABLE III
THE CLASSIFICATION RESULTS OF EEG SIGNALS RECORDED WHILE SOLVING HARD QUESTIONS IN CITY NOISE AND POPULAR MUSIC ENVIRONMENTS FOR ALL PARTICIPANTS

No of Participant	Accuracy	Precision
1	94.95	94.95
2	95.96	95.96
3	95.12	95.27
4	93.60	93.89
5	95.62	95.63
6	100	100
7	81.99	82.02
8	89.23	89.34
9	98.15	98.15
10	82.83	82.98
11	91.08	91.16
12	98.99	99.00
13	97.98	98.06
14	89.73	89.97
15	99.83	99.83
16	100	100
17	91.58	91.86
Average	**93.92**	**94.00**

The city noise and popular music environments are classified with success rate of 90% and above for 8 participants while performing simple cognitive tasks in spite of fact that the environments are classified with success rate of 90% and above for 13 participants while carrying out hard cognitive tasks.

4. CONCLUSIONS

In this study, we investigate the effects of city noise and popular music environments on EEG signals recorded during the solution of simple and hard questions. Results show that, the noise and favorite music environments during problem solving can be distinguished from each other, using the corresponding EEG signals, with high accuracy rates. Results also show that, accuracy rate is higher in classifying environments while solving hard problems. Considering this result, we may conclude that, people are more affected by the environment while solving hard problems than solving simple ones. This might be due to the engagement level the subject needs, which is expected to rise as the difficulty level of the problem increases. This specific topic will be investigated as a feature work.

ACKNOWLEDGMENT

The data used in this study were collected with the support of the Research Fund of Adana Alparslan Turkes Science and Technology University, grant number: 17103016.

REFERENCES

[1] S. G. Eraldemir, E. Yildirim, "Comparison of wavelets for classification of cognitive EEG signals", 23nd Signal Processing and Communications Applications Conference (SIU), 2015, pp. 1381-1384.

[2] S. G. Eraldemir, E. Yıldırım, "EEG Verilerinden Sayısal Ve Sözel Düşüncenin Sınıflandırılması". IEEE 22. İşaret İşleme ve İletişim Uygulamaları Kurultayı, 2014, pp.1-4.

[3] S. G. Eraldemir, M.T. Arslan, E. Yıldırım, "Investigation Of Feature Selection Algorithms On A Cognitive Task Classification: A Comparison Study", Balkan Journal of Electrical and Computer Engineering , Vol.6, No.2, 2018, pp. 99-104.

[4] N. Özdemir, E. Yıldırım, "Hılbert Huang Transform Ve Yapay Sinir Ağları İle Epileptik Nöbet Tahmini Epıleptıc Seızure Predıctıon Based On Hılbert Huang Transform And Artıfıcıal Neural Networks", Signal Processing and Communications Applications Conference (SIU), 2012 20th, pp.1-4.

[5] H. M. Mallikarjun, H. N. Suresh, "Depression level prediction using EEG signal processing," 2014 International Conference on Contemporary Computing and Informatics (IC3I), Mysore, pp. 928-933.

[6] A. Uçan, "İnsan ve Müzik, İnsan ve Sanat Eğitimi", Ankara: Müzik Ansiklopedisi Yayınları, 1996, p. 30.

[7] E. G. Duru, H. S. Köse, "Klasik Müzik Dinlemenin İlköğretim Öğrencilerinin Sınav Başarılarına Etkisi", e-Journalof New World Sciences Academy, 2011, Vol.7, No.2.

[8] E. Özdemir, S. Coşkuner, "Müzik Dinleme Etkinliklerinin İlköğretim Öğrencilerinin Akademik Başarısına Etkisi", Elementary Education Online, 2018, Vol.17, No.1, pp.57-69.

[9] H. Kumbur, N. Çoğunnu, "İçel'in Gürültü Kirliliği Envanterinin Çıkarılması", Türkiye'de Çevre Kirlenmesi Öncelikleri Sempozyumu III, Gebze Yüksek Teknoloji Enstitüsü, Kocaeli, 1999, pp.393-405.

[10] H. Kumbur, E. Yalçın, "Mersin'de Gürültü Düzeylerinin Yıllara Göre Değişimi ve Gürültü Kirliliği Haritasının Oluşturulması", GAP Çevre Kongresi, Şanlıurfa, 2000, pp.949-962.

[11] E. Debik, A. D. Altay, "İstanbul'da Trafik Kaynaklı Gürültü Kirliliğinin Boyutları", Türkiye'de Çevre Kirlenmesi Öncelikleri Sempozyumu III, Gebze Yüksek Teknoloji Enstitüsü, Kocaeli, 1999, pp.1081-1086.

[12] S. Erdogan, M. Dogan, İ. Yılmaz, M. Güllü, T. Baybura, M. Ulu, Ö. Sise, "Afyonkarahisar İl Merkezi Karayolu Trafik Gürültü Haritasının Hazırlanması", Afyon Kocatepe Üniversitesi Fen Ve Mühendislik Bilimleri Dergisi , Vol., No.2, 2007, pp.151-164 .

[13] D. M. Condon, W. Revelle, "The International Cognitive Ability Resource: Development and Initial Validation of a Public-Domain Measure," Intelligence, vol. 43, 2014, pp. 52-64.

[14] M.T. Arslan, S. G. Eraldemir, A. F. Koç, E. Yıldırım, "Farkli Ses Ortamlarinda Kognitif Işlemler Veritabani", II. International Scientific and Vocational Studies Congress, 2018, pp.1023-1029.

[15] P. S. Addison, "The Illustrated Wavelet Transform Handbook", Institute of Physics Publishing, 2002, p.12.

BIOGRAPHIES

Server Göksel Eraldemir obtained his BSc degree in Computer Education and Instructional Technology from the University of Ondokuz Mayıs (OMU), Turkey, in 2002. He received M.S. degree in electrical and electronics engineering from the University Mustafa Kemal, in 2014. He has been a Ph.D. student in Electrical-Electronics Engineering department in Adana Alparslan Turkes Science and Technology University since September 2019. His current research interests are biomedical signal processing and data mining.

Mustafa Turan Arslan received his BSc and M.S. degrees in Computer Engineering from Erciyes University in 2011 and 2016, respectively. Nowadays, he has been a Ph.D. student in Electrical-Electronics Engineering department in Adana Alparslan Turkeş Science and Technology University since February 2018. His current research interests are biomedical signal processing, data mining and artificial intelligence.

Esen Yıldırım received the B.S. degree in Electrical and Electronics Engineering from Cukurova University, Adana, Turkey, in 1997, and the M.S. and Ph.D. degrees in Electrical Engineering from University of Southern California (USC), Los Angeles, in 2000 and 2006, respectively. She is currently an Associate Professor of Electrical and Electronic Engineering, at Adana Alparslan Turkeş Science and Technology University, Adana, Turkey. Her general research interests include biomedical signal processing, epileptic seizure detection, functional connectivity, learning methods, and emotion recognition from physiological signals.

Filiz Koc received Doctor in Istanbul University School of Medicine-İstanbul/Turkey, and Ass. Prof. Dr. Department of Neurology and *Neurophysiology* from Cukurova University, Adana, Turkey. She is currently an Professor of Cukurova University School of Medcine, Department of Neurology, Adana, Turkey. Her general research interests include neuromuscular disease, spinal cord disease, neuropathology and neurogenetic.

THE SYNCHRONIZATION BEHAVIOR OF BASAL GANGLIA

Y. Cakir

Abstract-A network model of basal ganglia (BG) that comprises striatum, internal and external segments of globus pallidus, subthalamic nucleus, substantia nigra pars reticulate neuronal sub populations and thalamus is constructed. The dynamic behavior of network is investigated using Izhikevich neuron model. The influences of dopamine, the synaptic strength and the neuronal interconnection density on the synchronization behavior of the subpopulations are investigated. In the case of dopamine depletion, the increased striatal synchronization is observed. Considerable effect on the synchronization of other basal ganglia sub populations is not observed in the case of dopamine depletion. The highest synchronization values are observed for the lowest synaptic strength and the neuronal interconnection density. The decreased neuronal interconnection density causes a decrease in the fluctuation in synchronization in thalamic neurons depending on dopamine value.

***Keywords*—**basal ganglia, synchronization, Izhikevich neuron model

1. Introduction

THE basal Ganglia (BG), together with thalamus and cortex comprise a complex network that is responsible for variety of functions and dysfunctions. Basal ganglia has a key role in the abnormal neural oscillations, observed in Parkinson's disease or dystonia. Parkinson's disease is a neurodegenerative disorder whose patients experience motor deficits such as slowness of movement, rigidity, a low frequency rest tremor, and difficulty with balance and also non-motor deficits such as depression, constipation, pain, genitourinary problems, and sleep disorders. The motor deficits are due to the degeneration of dopamine containing neurons in the Substantia Nigra pars compacta (SNc) and consequent loss of dopamine in the striatum [1].

Neural activity in the brain of parkinsonian patients is characterized by the intermittently synchronized oscillatory dynamics [2]. In the patients with Parkinson's disease and in animal models of this disorder, the neurons in the basal ganglia and the related regions in thalamus and cortex show changes including altered firing rates and patterns, pathologic oscillatory activity and increased inter-neuronal synchronization [3]. Subthalamic Nucleus (STN), Globus Pallidus Internal (GPi), and Globus Pallidus External (GPe) neurons in the basal ganglia show high levels of synchrony in Parkinsonian conditions [4].

Yuksel Cakir is with Istanbul Technical University, Department of Electronics and Communication Engineering, Istanbul, Turkey and Strasbourg University, ICube IMAGeS, Strasbourg, France
(cakiryu@itu.edu.tr, ycakir@unistra.fr)

Manuscript received Jul. 17, 2019; accepted Sep. 12, 2019.
Digital Object Identifier:

More recent studies suggest the key role of the BG in "nonmotor" diseases such as absence epilepsy which is a generalized non-convulsive epilepsy. In these diseases, the symptoms accompany various oscillatory patterns of neural activity often synchronized across the BG, cortex and other brain areas [1]. Recent studies in animals and humans have revealed the existence of several types of oscillatory activity in the various nuclei of the basal ganglia and, although still poorly understood, are believed to play an important function in both the normal physiology and pathophysiology of this system [5].

On the other hand, Alzheimer's disease (AD) is the most prominent aging dependent neurodegenerative disorder. Brain atrophy caused by neuronal loss is a prominent pathological feature of Alzheimer's disease. Cholinergic neurons are most damaged in AD brain [6]. Reduction in potential healthy synapses and the strength of connections among the neurons is observed in case of AD [7].

Since in the case of brain diseases pathologies such as neuronal lost, dopamine depletion and reduction of synaptic strength is observed, in this work, the synchronization level of neuronal activity of Basal ganglia regions such as Striatum, GPi/SNr, GPe, STN and Thalamic relay neurons is investigated according to these pathologies. For different dopamine levels, different synaptic strength values and neuronal interconnection densities, the synchronization level is obtained and analyzed. The simulation results reveal that the striatal synchronization is increased in the case of dopamine depletion. For the lowest synaptic strength and the neuronal interconnection density, the highest synchronization values are observed.

2. Basal Ganglia and Thalamus Network Structure

The Basal ganglia region of network given in Fig. 1 consists of Striatum, Globus Pallidus External (GPe), Globus Pallidus Internal (GPi), Substantia Nigra pars reticulate (SNr) and Subthalamic Nucleus (STN) sub networks. GPi and SNr are different neuronal populations but in this work they are considered as a single GPi/SNr structure due to their closely related inputs and outputs and similarities in cytology and function [8].

The striatum sub network structure is as that defined in [9] but include the latest findings about the network structure given in [10]. The rate of Fast Spiking Interneurons (FSI) in the striatum is roughly 10 %. The half of the left 90 % consists of D1 dopamine receptor type Medium Spiny Neurons (MSN) and the other half of D2 dopamine receptor type MSN's. FSI neurons in the striatum has inhibitory

 ISSN: 2548-0650 http://dergipark.gov.tr/jcs

GABAergic connections with the other FSI neurons and D1 and D2 MSN neuronal population. Also, there is gap junction type connection between FSI neurons. The D2 MSN neurons has inhibitory GABAergic connection with other D2 MSN neurons, D1 MSN neurons population and GPe neurons. The D1 MSN neurons has inhibitory connections with the other D1 MSN neurons and GPi and SNr neuronal populations.
The GPe receives excitatory input from STN neurons and other GPe neurons over local axon collaterals which have an inhibitory influence. The GPe sends an inhibitory projection to GPi and to STN. The subthalamic nucleus is the only portion of the basal ganglia that produces an excitatory neurotransmitter glutamate which excites both the GPe and GPi/ SNr output nuclei.
The external inputs of Basal ganglia are Thalamocortical signal originating from cortex region and dopamine signal originating from SNc region that modulate the striatal neurons. Thalamus region in the network consists of Thalamocortical relay cells that receive excitatory sensorimotor inputs from cortex region. This neurons function is affected by inhibitory synaptic connections from GPi/SNr basal ganglia neuronal population. The striatal activity has excitatory effect on the thalamus via the D1 MSN neurons connection from the striatum to the output nuclei called direct pathway, and an inhibitory effect via the D2 MSN neurons connection to the output nuclei over GPe and the STN called indirect pathway [8, 11, 12].

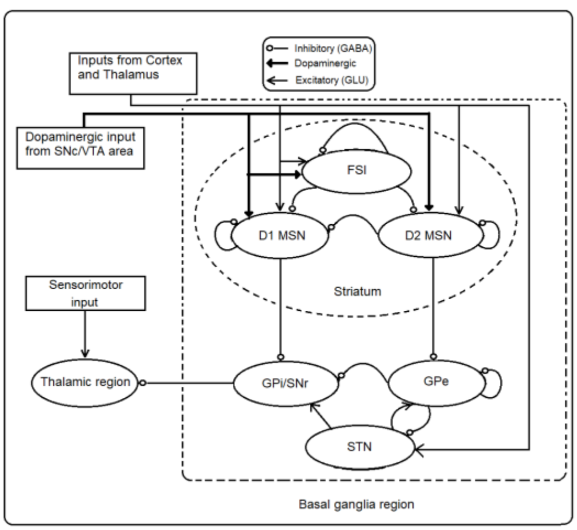


Fig. 1. Structure of Basal ganglia thalamocortical network

3. IZHIKEVICH NEURA MODEL

The neuronal populations of Basal ganglia and Thalamus are modeled by using phenomenological *Izhikevich* model given in Eq. 1 [9,13,14].
Here C is the membrane capacitance. The dimensionless variables v and u represent the membrane potential of the neuron and the membrane recovery, respectively. v_r, v_t are the resting and threshold potentials.

$$C\dot{v} = k(v - v_r)(v - v_t) - u + I$$
$$\dot{u} = a[b(v - v_r) - u] \quad (1)$$
$$v \geq v_{peak} \quad v \to c, u \to u + d$$

a, *b*, *c*, and *d* are dimensionless parameters. v and u account for the activation and inactivation of ionic currents, respectively. When the membrane potential reaches vpeak, the values of v and u are assigned with *c* and u+d as given in the last expression of Eq. 1. [9, 13, 14]. I denotes the currents consisting of the externally applied and the synaptic current, $(I = I^{out} + I^{syn})$. The externally applied current represents the effects of inputs coming from outside of the network. All populations in network consist of 100 neurons connected randomly by predefined connection probability.
The striatum region neurons are affected by dopamine neuromodulator. Dopamine inhibits the D2 dopamine receptor type MSNs in the indirect pathway and excites D1 dopamine receptor type MSNs in the direct pathway [15]. The FSI and D1 and D2 MSN neuron models of Striatum region are as:

$$C\dot{v}_{fs} = k\lfloor v_{fs} - v_r(1 - \eta\phi_1)\rfloor(v_{fs} - v_t) - u_{fs} + I \quad (2)$$

$$\dot{u_{fs}} = \begin{cases} -au_{fs}, & if \;\; v_{fs} < v_b \\ a\left[b(v_{fs} - v_b)^3 - u_{fs}\right], & if \; v_{fs} > v_b \end{cases} \quad (3)$$

$$C\dot{v}_{D1} = k(v_{D1} - v_r)(v_{D1} - v_t) - u + I + \phi_1 g_{DA}(v_{D1} - E_{DA}) \quad (4)$$

$$C\dot{v}_{D2} = k(1 - \alpha\phi_2)(v_{D2} - v_r)(v_{D2} - v_t) - u + I \quad (5)$$

where the reset condition of D1 and D2 MSN neurons is as that given in Eq. 1.
Dopamine has a dual action on MSNs; it inhibits the (D2-type) MSNs and excites (D1-type) [15]. $\phi_1 g_{DA}(v_{D1} - E_{DA})$ in D1 MSN neuron model is for simulating the hyperpolarizing effect of D1 activation and $k(1 - \alpha\phi_2)$ in D2 MSN neurons is for reflecting increased sensitivity to the injected current where ϕ1 and ϕ2 are the parameters for specifying the level of dopamine, taking value between 0 and 1. The external current is modeled as

$$I^{out} = I_o + \rho\alpha_i(t) + \sigma I_{cortical} \quad (6)$$

where Io , ρ and σ are the constants, α(t) is white noise with zero mean value and $I_{cortical}$ is a pulse shaped signal with unit amplitude and frequency of 2 spike/s, simulating cortical input [15]. The synaptic input to all MSNs is $I^{syn} = I_{gaba-fs} + I_{gaba-ms}$.
The internal synaptic current of any neuron is the sum of exponentially decaying presynaptic currents of connected neurons, which reach to considered neuron with a delay. The synaptic current of any i'th MSN neuron of type Ii=Igaba_fs + Igaba-ms is given in Eq. 7.

$$I_i(t) = g_{gaba\_fs} \sum_l r_{il}(t-\tau_{il})[E_{gaba\_fs} - V_i] - g_{gaba\_ms} \sum_j r_{ij}(t-\tau_{ij})[E_{gaba\_ms} - V_i] \quad (7)$$

where ggaba_fs and ggaba_ms are the chemical conductivity strengths, and τil and τij represents time delays from l'th and j'th presynaptic neurons to i'th postsynaptic neuron. Time delay between striatal neurons was assumed zero during analysis in this work. Egaba_fs and Egaba_ms are the reversal potentials for the inhibitory synapses and was taken as Egaba_fs = Egaba_ms =- 60 mV. For each spiked connected neuron, (jth connected to ith neuron), the connection strength between these neurons is updated as $r_{ij} \leftarrow r_{ij} + \omega_{ij}$, here ωij is the inhibitory synaptic strength from neuron j to neuron i. It is taken as constant, ωij =ω [9, 14, 16].

rij is the dynamic variable that decreases exponentially depending on decay time (synaptic time constant) τs=τgaba_*fs*=τgaba_ms as given in Eq. 8.

$$\tau_s \dot{r}_{ij} = -r_{ij} \quad (8)$$

The gap junction type connection between FSI neurons provide an extra current of electrical type and is included in the model as I_{gap}. The synaptic input for FSI neurons is as:

$$I^{syn} = I_{gaba-fs}(1 - \varepsilon\phi_2) + I_{gap} \quad (9)$$

where $(1 - \varepsilon\phi_2)$ represents dopamine effect and junction current for any i'th FSI neuron is defined as is in Eq. 10.

$$I_i\ (t) = g_{gap} \sum_k [V_k - V_i] \quad (10)$$

Here ggap is the constant electrical synaptic strength from neuron *k* to *i*. Vk and Vi are pre and postsynaptic neuron's membrane potential.

By using the simplified form of Izikhevich neuron model given in Eq. 11, the rest of basal ganglia network is constructed [8].

$$\begin{aligned} \dot{v} &= 0.04v^2 + 5v + 140 - u + I \\ \dot{u} &= a(bv - u) \\ &if\ v \geq 30\ mV, then\ v \to c, u \to u + c \end{aligned} \quad (11)$$

As in the striatal neurons, the input current $I_i = I_i^{app} + I_i^{syn}$ of any i'th neuron in the rest of basal ganglia consists of the external applied current I^{app} and the summation of synaptic currents coming from other neurons having synaptic connections with it expressed as I_i^{syn}. The external currents for GPi/SNr, GPe and STN populations are constant valued, whereas the externally applied current to Thalamus region is puls shaped signal with frequency of 14Hz comprising sensorimotor input (ISM) to this region. The synaptic current is in the form of

$$I_i^{syn} = \sum_j I_{ij}^{syn} = \sum_j g_{ij} r_{ij}(t - \tau_{ij})[E_S - V_i] \quad (12)$$

where the synaptic current from j'th neuron to i'th neuron has coupling strength denoted as g_{ij} and τ_{ij} denotes synaptic delay time between pre and postsynaptic neurons and E_S is reversal potential that is $E_S = 0\ mV$ for excitatory and $E_S = -80mV$ for inhibitory connection. The update mechanism of connection strength r_{ij} between pre and postsynaptic neurons is the same as update process in striatum neurons. Beside striatal neurons, the synaptic delay time between pre and postsynaptic neurons in the basal ganglia are taken as described in [8]. The striatum region neuron parameters used in analysis are chosen as that described in [9] and are given in Table 1.

TABLE 1
PARAMETERS FOR FSIS AND MSNs

Parameters for FSI neurons		Parameters for MSN neurons	
a	0.2	C	50 pF
b	0.025	b	-20
d	0	c	-55 mV
k	1	v_r	-80 mV
v_{peak}	25 mV	v_{peak}	40 mV
v_b	-55 mV	k	1.14
C	80 pF	v_t	-33.8 mV
c	-60 mV	a	0.05
v_r	-70 mV	d	377
v_t	-50 mV	α	0.03
η	0.1	g_{DA}	22.7 nS
ε	0.625	E_{DA}	-68.4 mV
E_{gaba_fs}, E_{gaba_ms}	-60 mV	E_{gaba_fs}, E_{gaba_ms}	-60 mV
τ_{gaba_fs}	4 mS	τ_{gaba_fs}, τ_{gaba_ms}	4 mS
g_{gaba_fs}	20 nS	g_{gaba_ms}	4.36 nS

The network parameters of the Thalamus and other sub population of Basal ganglia, including GPi/SNr, GPe and STN neuronal populations was given in Table 2 and 3.

TABLE 2
GPi/SNr, GPe STN AND THALAMUS NEURONAL POPULATION'S NEURON PARAMETER VALUES

Population	a	b	c	d	τ_s ms	E_s mV	I^{app}
GPe	0.01	0.58	-65	4	5	-80	10
GPi/SNr	0.01	0.58	-65	4	100	-80	15
STN	0.01	0.26	-65	2	10	0	1
Thalamus	0.01	0.23	-65	0.45	10	0	I_{SM}

The parameters values are determined by considering the recent studies on the basal ganglia neurons dynamics and [8, 9, 12] to simulate the neuronal firing rates and patterns. Different from [8], the present network includes the detailed striatum sub network whereas in [8], the striatum is depicted as an external input only. The basal ganglia thalamic network in [12] is mass modeled whereas the present network structure includes Izhikevich neuron-based network model of basal ganglia region.

TABLE 3
THE CONNECTIVITY RELATIONS BETWEEN SUB NETWORKS

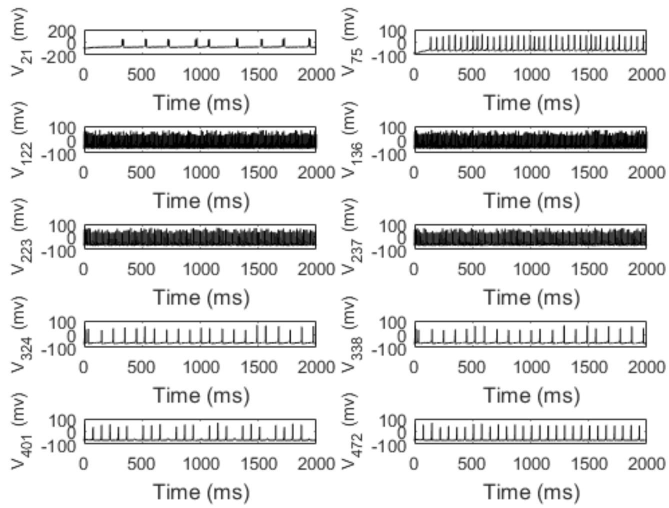
Connectivity, α→β	Synaptic conductance, g
MSN D1 → GPi/SNr	0.75
MSN D2 → GPe	0.75
STN → GPi/SNr	0.075
STN → GPe	0.075
GPe → STN	0.025
GPe → GPe	0.025
GPe → GPi	0.015
GPi →Thl	0.01

4. SIMULATION RESULTS

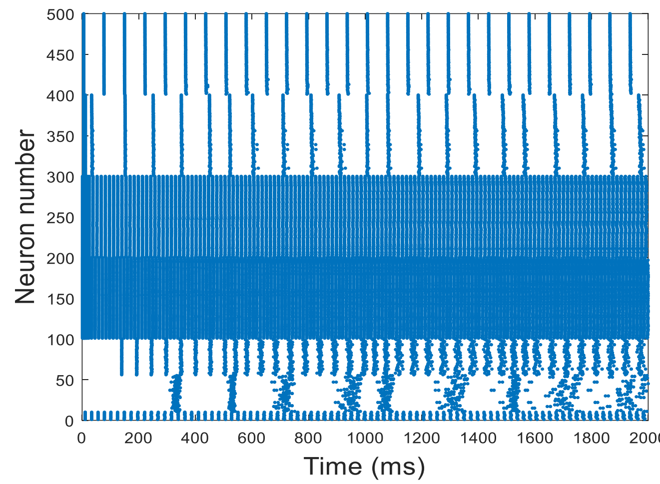
Since in the case of diseases such as Alzheimer's and Parkinson's disease, the neuron death, the synaptic connectivity degenerations and decrease in dopamine level is observed, the synchronization in the neuronal populations is analyzed by changing the synaptic connectivity number and the synaptic strength and by reducing the amount of dopamine. The degree of synchrony in the network is calculated according to the method developed by Hansel and Sompolinsky [17]. The synchronization measure is computed as:

$$S = \frac{\frac{1}{T}\sum_{t=1}^{T}\left[\left(\frac{1}{N}\sum_{i=1}^{N}V_i(t)\right)^2\right]-\left[\frac{1}{T}\sum_{t=1}^{T}\left(\frac{1}{N}\sum_{i=1}^{N}V_i(t)\right)\right]^2}{\frac{1}{N}\sum_{i=1}^{N}\left[\frac{1}{T}\sum_{t=1}^{T}V_i(t)^2-\left(\frac{1}{T}\sum_{t=1}^{T}V_i(t)\right)^2\right]} \qquad (13)$$

The neuronal activity of some neurons obtained for $\phi 1$ = $\phi 2$=1 comprising normal level of dopamine are given in Fig. 2a as an example of neuronal activity of network.
The network populations connectivity is obtained for the probability value of 0.1, i.e. any neuron has a connection probability of 0.1 to other and synaptic strength as wij=0.01. The firing pattern of all neurons in the network is given in Fig. 2b. The first 10 neurons are striatal FSI neurons, the following 45 neurons are D1 MSN (neurons number 11-55) and the next 45 neurons are D2 MSN neurons (neurons number 56-100). The neurons from 101 to 200 are GPi/SNr, neurons from 201 to 300 are GPe, neurons from 301 to 400 are STN and the last 100 neurons are Thalamic relay neuronal populations. It is seen that dopamine has different effect on D1 and D2 MSN neurons firing, and because of the applied 14 Hz external sensorimotor signal, the thalamic relay neurons fires approximately at this frequency.



a)



b)

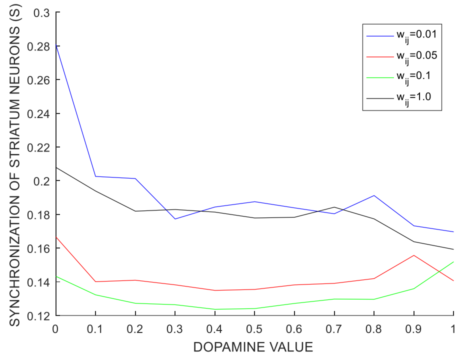
Fig. 2

a) The neuronal activity of randomly selected neurons,

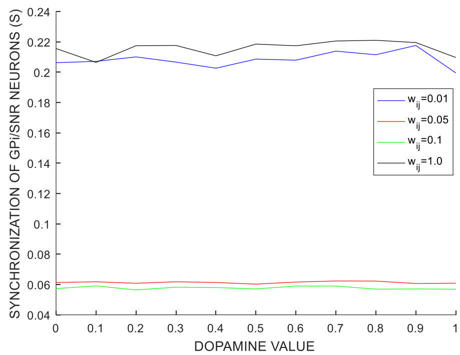
b) the raster plot of network obtained for connection probability of 0.1, dopamine level

$\phi 1$ =$\phi 2$=1 and wij=0.01

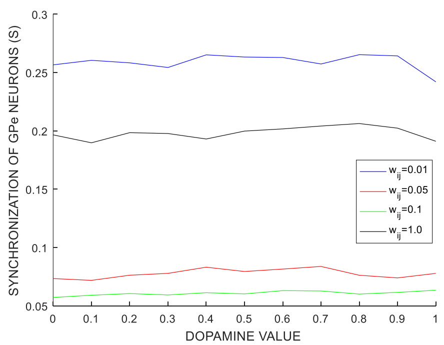
By decreasing the connection probability from 0.5 to 0.1 for 2000 ms, the network activity was obtained for striatal neurons synaptic strength wij values of 1.0, 0.1, 0.05 and 0.01 and dopamine values between $\phi 1$ =$\phi 2$=0 (comprising total dopamine depletion) and $\phi 1$ =$\phi 2$=1 (comprising no lack of dopamine). The synchronization measure, S for these parameter values are calculated.
The obtained synchronization measure is the mean value of the synchronization values of 5 different networks randomly generated with above mentioned connection probabilities. The obtained results are given in Fig. 3, 4 and 5.



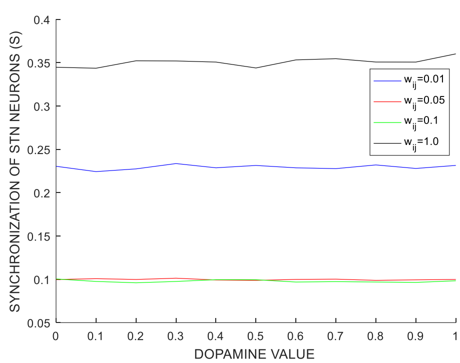
a)



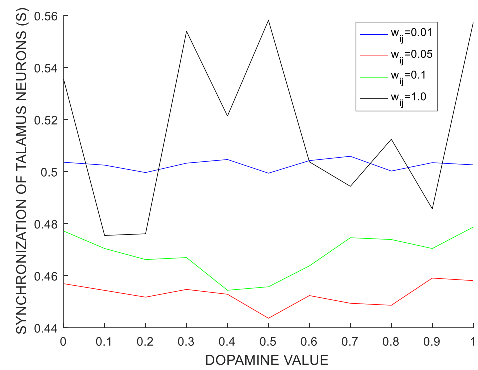
b)



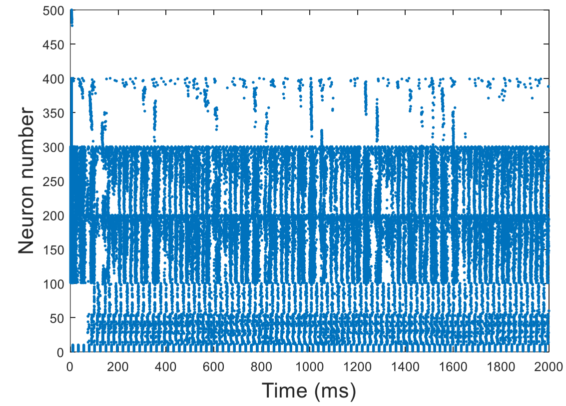
c)



d)

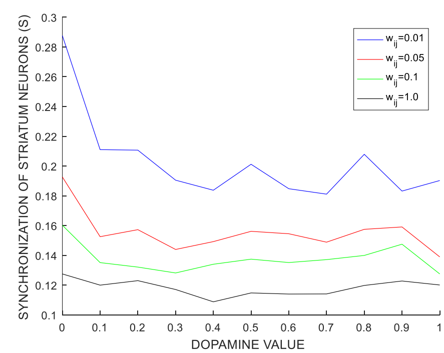


e)

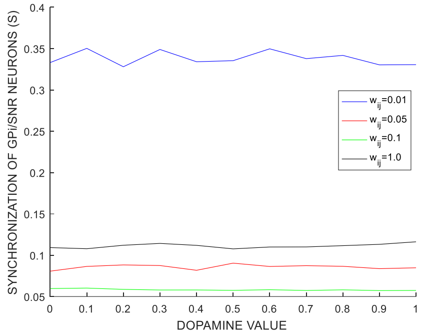


f)

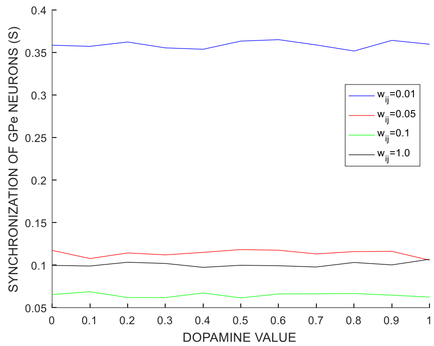
Fig. 3. Synchronization measure (S) versus dopamine value obtained for connection probability of 0.5.
a) Synchronization of striatal neurons population,
b) Synchronization of GPi/SNr neurons population
c) Synchronization of GPe neurons population
d) Synchronization of STN neurons population
e) Synchronization of Thalamic neurons population
f) Rasterplot of network.



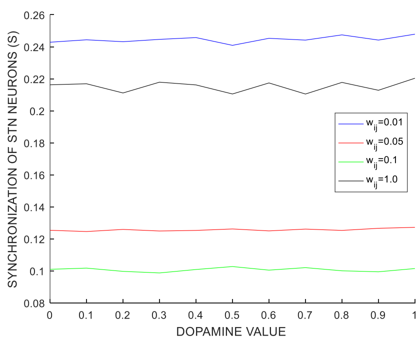
a)



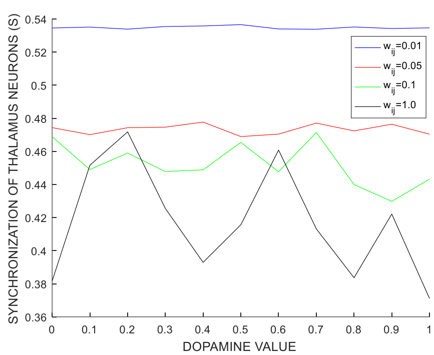
b)



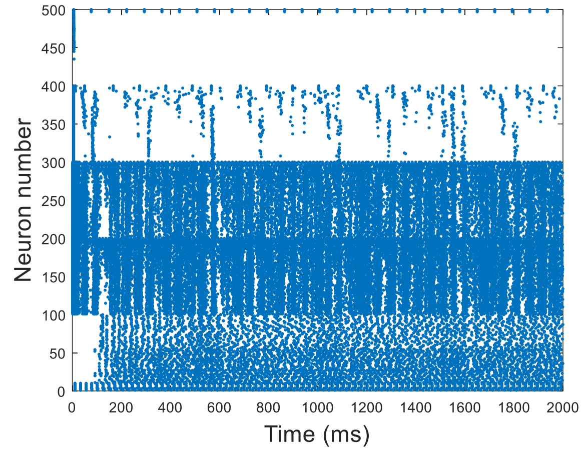
c)



d)

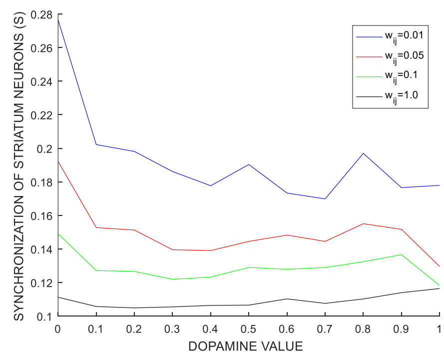


e)

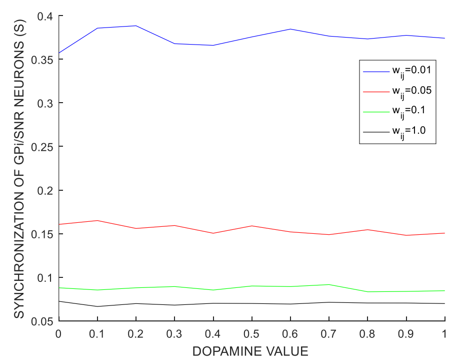


f)

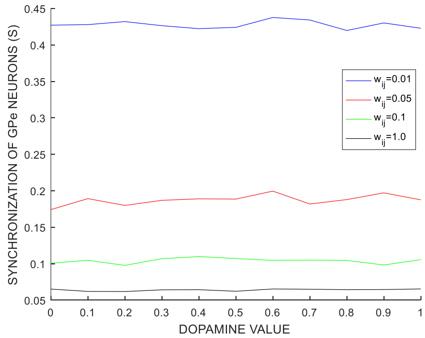
Fig. 4. Synchronization measure (S) obtained for connection probability 0.25.
a) Synchronization of striatal neurons population,
b) Synchronization of GPi/SNr neurons population,
c) Synchronization of GPe neurons population,
d) Synchronization of STN neurons population,
e) Synchronization of Thalamic neurons population,
f) Rasterplot of network.



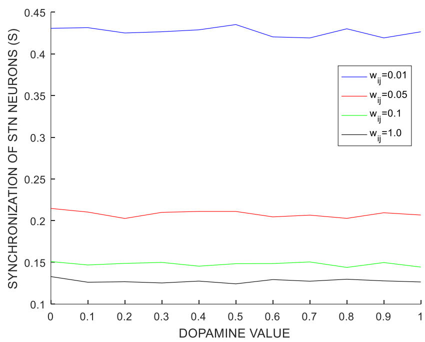
a)



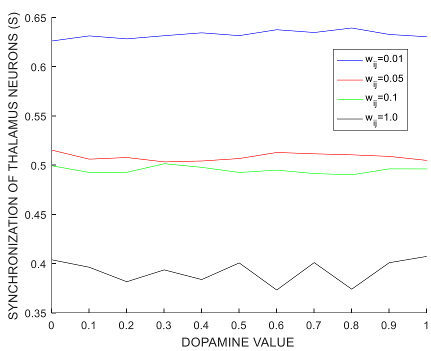
b)



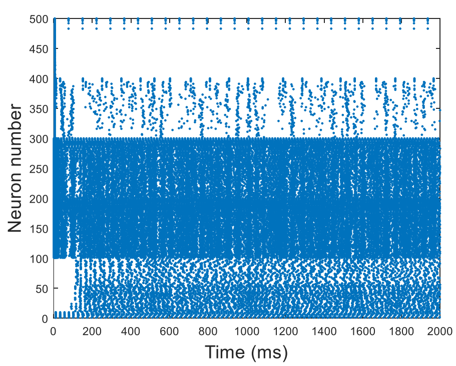
c)



d)



e)



f)

Fig. 5. Synchronization measure (S) obtained for connection probability 0.1.
a) Synchronization of Striatal neurons population,
b) Synchronization of GPi/SNr neurons population,
c) Synchronization of GPe neurons population,
d) Synchronization of STN neurons population,
e) Synchronization of Thalamic neurons population,
f) Rasterplot of network.

As seen from synchronization values obtained for different connectivity values, different synaptic strength and dopamine values,

a) Decreasing the value of dopamine from its normal value of $\phi_1 = \phi_2 = 1$ to $\phi_1 = \phi_2 = 0$ increases the synchronization in striatal population which is the phenomena observed in the disease such as Parkinson in which neurophysiological hallmark is excessive synchronous activity in the basal ganglia (BG) network [8].

b) Decreasing the connection probability causes a decrease in the fluctuation in synchronization measure in thalamic neurons depending on the dopamine value. For higher synaptic strength as $w_{ij}=1$, depending on the dopamine value, the synchronization is high for connection probability of 0.5 (Fig. 3e). Decreasing connection probability to 0.1 causes a decreased fluctuation in the synchronization measure of thalamic neuron population depending on the dopamine value (Fig. 5e).

c) The synchronization measure in GPi/SNr, GPe and STN populations do not change so much depending on the dopamine decrease. For low connection probability value such as 0.1, the higher synchronization measure values are obtained for lower synaptic strength values.

d) From the rasterplots obtained from the activation for different connection probability values, it is seen that the firing in thalamic neurons decreases for higher connectivity values that means the increased inhibition is the result of higher connectivity value.

5. Conclusion

The synchronization behavior of basal ganglia is investigated by using Izhikevich neuron model. Basal ganglia comprises striatum, internal and external segments of globus pallidus, subthalamic nucleus, substantia nigra pars reticulate neuronal sub populations and thalamus. The influences of dopamine, synaptic strength and neuronal interconnection density on the synchronization behavior of the subpopulations are investigated. It is known that the neurophysiological hallmark of PD is excessive synchronous activity in the basal ganglia network. The simulation results reveal that the striatal synchronization is increased in the case of dopamine depletion which is consistent with experimental observations [8]. The decrease in the dopamine level has not shown considerable influence on the synchronization of other basal ganglia sub populations. The highest synchronization values are observed for the lowest synaptic strength and neuronal interconnection density. Decreased neuronal interconnection density causes a decrease in the fluctuation in synchronization in thalamic neurons depending on dopamine value.

ACKNOWLEDGMENT

This work is supported by TUBITAK BIDEB (2219)

REFERENCES

[1] T. Arakaki, "Collective dynamics of basal ganglia-thalamo-cortical loops and their roles in functions and dysfunctions", Neurons and Cognition [q-bio.NC]. Université Pierre et Marie Curie - Paris VI, 2016. English.

[2] Park, L. L. Rubchinsky, "Potential Mechanisms for Imperfect Synchronization in Parkinsonian Basal Ganglia", PLOS ONE, Volume 7 , Issue 12, 2012 , pp. 1-12.

[3] Galvan, A. Devergnas, T. Wichmann, "Alterations in neuronal activity in basal ganglia-thalamocortical circuits in the parkinsonian state", Frontiers in Neuroanatomy, Vol. 9 Art. 5, 2015, pp.1-21.

[4] Mandali, M. Rengaswam, V.S. Chakravarthy, A. A. Moustafa, "A spiking Basal Ganglia model of synchrony, exploration and decision making", Frontiers in Neuroscience, Vol. 9, Art. 191, 2015 , pp.1-21.

[5] W. D. Hutchison, J. O. Dostrovsky, J. R. Walters, R. Courtemanche, T. Boraud, J. Goldberg, P. Brown, "Neuronal Oscillations in the Basal Ganglia and Movement Disorders: Evidence from Whole Animal and Human Recordings", The Journal of Neuroscience, 24(42), 2004, pp. 9240 –9243.

[6] T. Niikura, H. Tajima, Y. Kita, "Neuronal Cell Death in Alzheimer's Disease and a Neuroprotective Factor, Humanin", Current Neuropharmacology, 4, 2006, pp.139-147.

[7] G. Kashyap, D. Bapat, D. Das, R. Gowaikar, R. E.Amritkar, G. Rangarajan, V. Ravindranath, G.Ambika, "Synapse loss and progress of Alzheimer's disease -A network model", Scientific Reports, 9: 6555, 2019, pp.1-9.

[8] Liu, J. Wanga, H. Yua, B. Denga, X. Weia, H. Lic, K. A. Loparob, C. Fietkiewicz, "Dynamical analysis of Parkinsonian state emulated by hybrid Izhikevich neuron models", Commun Nonlinear Sci Numer Simulat., Vol. 28, 2015, pp. 10–26.

[9] Y. Cakir, "Modeling influences of dopamine on synchronization behavior of striatum", Network: Computation in Neural Systems, Vol. 28, No 1, 2017, pp. 28-52.

[10]

[11] C.R. Gerfen, D.J. Surmeier, "Modulation of striatal projection systems by dopamine", Annu Rev Neurosci., 34, 2011, pp. 441–466.

[12] M.D. Humphries, J. Obeso, J.K. Dreyer, "Insights into Parkinson's disease from computational models of the basal ganglia", Neurol Neurosurg Psychiatry, 89, 2018, pp.1181–1188.

[13] S. J. van Albada, P. A. Robinson, "Mean-field modeling of the basal ganglia-thalamocortical system. I Firing rates in healthy and parkinsonian states", Journal of Theoretical Biology, Vol. 257, 2009, pp. 642–663.

[14] E.M. Izhikevich, "Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting", The MIT Press Cambridge, Massachusetts, London, England. 2007.

[15] Y. Cakir, "Modeling of synchronization behavior of bursting neurons at nonlinearly coupled dynamical networks" Network: Computation in Neural Systems, Vol.27 No. 4, 2016, pp. 289-305.

[16] D. Humphries, R. Wood, K. Gurney, "Dopamine-modulated dynamic cell assemblies generated by the GABAergic striatal microcircuit", Neural Networks, Vol. 22, No. 8, 2009, pp. 1174-1188.

[17] Guo, Q. Wang, M. Perc, "Complex synchronous behavior in interneuronal networks with delayed inhibitory and fast electrical synapses", Phys Rev E., Vol. 85, 061905, 2012, pp. 1-8.

[18] Hansel, H. Sompolinsky, "Synchronization and Computation in a Chaotic Neural Network", Phys Rev Lett., Vol. 68, No. 5, 1992, pp.718–721.

BIOGRAPHY

Yuksel Cakir received B.Sc. degree from Istanbul Technical University; Faculty of Electrical and Electronics Engineering, Electronics and Communication Engineering Department and he received M.Sc. degree from Institute of Science and Technology, Computer and Control Engineering Department, and Ph.D. degree from the same institute Electronics and Communication Engineering Department. He joined Istanbul Technical University, Electronics and Communication Department as research assistant in 1987, where he is now associate professor. He worked as visiting scientist at Strasbourg University, ICube IMAGeS Laboratory in 2018–2019. His research interests include non-linear dynamical systems, artificial neural networks and computational neuroscience.

A USABILITY RESEARCH ON TASK PREDICTION FOR EXPERIENCED USERS WITH COGTOOL

K. Arık

Abstract— Rapidly developing technology has offered different alternatives to human beings and the main target of those alternatives has been to respond to human needs. In this process, use of technology has become widespread, but it has brought some problems due to individual differences, digital competencies and generational differences. Conducting an effective process in solving those problems has also increased importance of "Human - Computer Interaction" workspace. It's not possible to evaluate users as uniform in technology human scope. Undoubtedly, in human computer interaction, user is often assumed to be "human." Cognitive modeling practices have started to be associated with many fields, from fields of psychology, engineering sciences and economics. Over 80% of articles in major theoretical journals of Cognitive Science include cognitive modeling. This research provided by 10 participants, 4 male and 6 female users who actively use Garanti BBVA Bank mobile application. Accordingly, problem of research is to prediction on whether CogTool tool makes a true accurate prediction by participants performing tasks in line with some tasks. KLM, GOMS and other cognitive models are similar to an efficient mean to exclude the application of this process was investigated. According to research results; average time of participants to perform Task 1- 5.54 sec the lowest 4.14 sec and the highest 6.69 sec, average time for Task 2- 8.67 sec the lowest 7.59 sec and the highest 9.45 sec and Task 3- 11.60 sec was in the lowest 10.62 sec and the highest in 13.21 sec. Respectively, CogTool estimates for tasks performed were 6.1 secs for Task 1, 9.9 secs for Task 2 and 12.1 secs for Task 3. Accordingly, difference between real-time experience and CogTool predictions was measured as 0.56 sec in Task 1, 1.23 sec in Task 2 and 0.50 sec in Task 3. In the light of those findings, it's seen CogTool tool predicts real-time results with a minor rate of error compared to average time in assigned tasks.

Keywords— *CogTool, Usability, Cognitive Modeling, Experienced User*

1. INTRODUCTION

It's not possible to evaluate users as uniform in technology human interaction. Individual differences emerge as an important factor as is known. Users needed to meet their needs more easily over time, and they have been using technology more effectively in most of their daily life. For example, while users must wait at the bank to perform their financial transactions in before, due to active use of technology, this process can now be carried out more easily in mobile application. With another example, whenever a person wants to buy any product, it can be ordered from the Internet and get it, or even return it if doesn't like it.

Kaan Arık. is with Digital Game Design Department of Art and Design Faculty Beykoz University, Istanbul, Turkey, (e-mail: kaanarik@beykoz.edu.tr).

Manuscript received Aug 16, 2019; accepted Oct 18, 2019.
Digital Object Identifier:

The term of "Human Computer Interaction" in literature aims to provide "transparent" information to users also, shape information and communication technologies according to human needs in practice and theory [1,2]

Çağıltay [3] has defined interaction of users as a structure that aims to make technology aimed at people, not technology. The basis of structure is making basic elements more usable and accessible in terms of technology's service. Turkey's acquaintance with technological devices started in 1993 when UN (United Nations) provided computer and internet access to many countries [4,5].

In this period, technological tools such as computer, mobile phone and internet were used for testing in certain regions of Turkey. Turkey in the 2000s to correct Panasonic, Motorola and people began to become acquainted through phone companies such as Nokia and may use more. However, users have been unfamiliar with using technology and had difficulty in this adaptation process.

Tendency of individuals from every audience to use technology has made studies in this field important. Surely, in field of Human Computer Interaction, user is often assumed to be "human". This element also constitutes vast majority of concept that defines HCI (Human Computer Interaction). In terms of software or hardware component of some technological products, situations where you cannot select target audience or have different individual characteristics of target audience may arise. For example; Scratch application, which aims to develop software and algorithm skills for primary and secondary school students, while taking orders in banks, loading credit / money on your public transport card, or withdrawing money from ATM devices, while using kiosk devices developed to load card in a university refectory.

It can be grouped as a special audience. The change of intended group also differentiates interfaces to be designed. In addition, developing an interface to general or specific audience also reveals need to consider different areas that can be associated with HCI. At this point, research fields related with HCI are cognitive science, sociology, anthropology, artificial intelligence, information systems, graphic design, software and engineering.

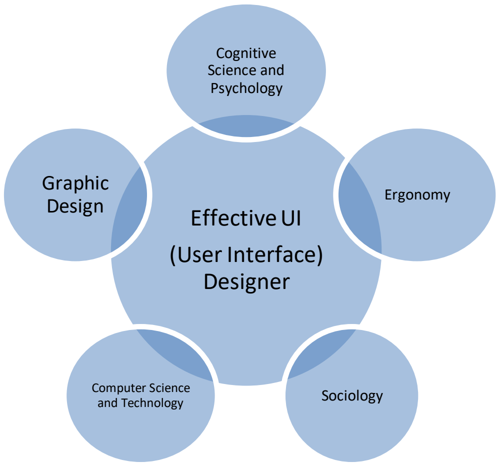


Fig.1. HCI and interactive workspaces [6]

2. Literature review

2.1. HCI and Cognitive Science

Human Computer Interaction (HCI) is the science of designing an interface that is usable, understandable and responsive to requests [7]. Besides being usable and accessible, it's also a necessary structure for establishment of reliable systems.

Dreyer [8] cognitive science in psychology dictionary; defined as interdisciplinary field of science that integrates knowledge and techniques of cognitive psychology, philosophy of logic, epistemology, anthropology, psycholinguistics, neuroscience and computer science in understanding mind and mental processes. Since research problems and techniques cover many sub-disciplines, it has been difficult to define cognitive science [9].

It's known that is a field performs interdisciplinary studies with different disciplines in field of Human Computer Interaction. As seen in Figure 1, HCI is used in cognitive science and psychology problem solving skills, developing designs that are suitable for ergonomics, physical skills, anthropology and sociology interaction in terms of wider contexts, computer science and technology to establish necessary technological connection and graphic design to provide an effective interface design. [6].

Among fields mentioned above, ones that stand out in terms of social sciences can be listed as psychology and cognitive science. Cognitive science stands out as a field that deals with only cognitive processes of individuals, among structures divided into 3 groups as cognitive, affective and psychomotor. Cognitive science, in which studies began to be introduced into the literature in the 1960s, has become one of study areas that can be associated with the field of Human Computer Interaction. The evaluation of cognitive science as a sub-branch of psychology since 1980s has limited its practices in this field in a sense [10]. It was emphasized that literature in HCI and cognitive science is limited, and cognitive science is important for studies of HCI.

2.1. HCI-Cognitive Science History and Relation

When looking at history of humanity, important inventions have feature of being developed due to human needs. An example of that is invention of computer, development of a waterless car engine and development of different weapon technologies. However, it's worth noting that computer was originally developed to perform calculations in the military field and serves different purposes for the future. During WWII, Britain and United States appointed a team of academicians who worked in psychology to develop more effective and faster methods of training more soldiers and fighter pilots. Researchers who provided some trainings, realized that the machines individuals are trained to use can be developed using a different way [11].

Advocating that sub-disciplines of cognitive science should be brought together, like other researchers [9] emphasized there is a common area in interface design in HCI. It also suggests this content can prove a way to combine cognitive sub-disciplines in ways never seen before. At this point, main target was to investigate productive component of the unifying theme of HCI and content proposed for cognitive science. Practical research also removes artificiality of scientific research in the perspective of Human Computer Interaction and Cognitive Science [12].

Scientists Fredick Bartlett, Donald Broadbent, Alphanse Chapenis and Paul Fitts at the University of Cambridge conducted cognitive studies to practice in this field. Next period, Broadbent and Miller continued their studies in academic world and establish foundation of cognitive science. Studies have led to increased interest in the cognitive dimensions of the underlying causes of human behavior in development of applied sciences. In this regard, foundations of cognitive science have been started to be laid. In terms of HCI, computer innovations such as text editing, graphic processing, interfaces, and pointing devices have paved the way for gradual identification [13].

When first examples of human computer interaction and Cognitive Science studies were examined, HCI focused on more applications, cognitive science focused more on theoretical parts. In ongoing process, they brought together Human Computer Interaction and Cognitive Science disciplines and introduced a new idea for application [14]. Cognitive Science focuses more on examining cognitive process that HCI is going through. In other words, it took into account processes of perception, use and decision making. In this understanding phase, interaction between computer and user is estimated and explained. In two areas, computer scientists and experts in cognitive science collaborate jointly. Cognitive science and HCI are getting help from most of each other and are improving day by day. At the point of solution, it is not a solution to cognitive science theories to HCI, but to allow new theories arising from the applied HCI research is offered as a solution to this problem.

Advocating that sub-disciplines of cognitive science should be brought together, like other researchers [9] emphasized there is a common area in interface design in HCI. It also suggests this content can prove a way to combine cognitive sub-disciplines in ways never seen before. At this point, main target was to

investigate productive component of the unifying theme of HCI and content proposed for cognitive science. Practical research also removes artificiality of scientific research in the perspective of Human Computer Interaction and Cognitive Science [12].

Scientists Fredick Bartlett, Donald Broadbent, Alphanse Chapenis and Paul Fitts at the University of Cambridge conducted cognitive studies to practice in this field. Next period, Broadbent and Miller continued their studies in academic world and establish foundation of cognitive science. Studies have led to increased interest in the cognitive dimensions of the underlying causes of human behavior in development of applied sciences. In this regard, foundations of cognitive science have been started to be laid. In terms of HCI, computer innovations such as text editing, graphic processing, interfaces, and pointing devices have paved the way for gradual identification [13].

When first examples of human computer interaction and Cognitive Science studies were examined, HCI focused on more applications, cognitive science focused more on theoretical parts. In ongoing process, they brought together Human Computer Interaction and Cognitive Science disciplines and introduced a new idea for application [14]. Cognitive Science focuses more on examining cognitive process that HCI is going through. In other words, it took into account processes of perception, use and decision making. In this understanding phase, interaction between computer and user is estimated and explained. In two areas, computer scientists and experts in cognitive science collaborate jointly. Cognitive science and HCI are getting help from most of each other and are improving day by day. At the point of solution, it is not a solution to cognitive science theories to HCI, but to allow new theories arising from the applied HCI research is offered as a solution to this problem.

2.3. Cognitive Modeling

Cognitive models are increasingly emerging in all areas of cognition, from perception to memory, to problem solving and decision making. Cognitive science is about understanding processes that the human brain uses to perform complex tasks such as perception, learning, remembering, thinking, guessing, inference, problem solving, decision making, planning and moving around the environment. Over 80% of articles in major theoretical journals of Cognitive Science include cognitive modeling [15].

Cognitive modeling practices have started to be associated with many fields, from psychology, engineering and economics. Thus, cognitive modeling becomes a basic tool for Cognitive Science and Social Sciences. Main purpose of a cognitive model is to scientifically explain one or more of those basic cognitive processes, or to better understand how those processes interact. In other words, cognitive modeling is one of the ways to evaluate usability of a product and those cognitive theories can solve problems by applying them. [16]. Cognitive modeling are models developed to design the interface more active and effectively.

Cognitive modeling appears as a structure that examines how individuals categorize perceptual objects in mind. For example, an individual who is an art enthusiast wants to know about the period of a painting, a scientist working in the field of social sciences, academic period of the subjects he worked on. In other words, cognitive modeling can be called the prototype of a categorization process [15]. Different models have been developed for cognitive modeling according to their usage in various fields.

For example, when we think that user should perform a task, process of understanding how an individual learns and how categorizes it in process of performing this task should be well known. This process can only be understood by scientific studies. In this respect, HCI and cognitive science need each other. Cognitive modeling is psychology-based, and also appears as a study tool in engineering for both theoretical research and practice. If the theory is well-structured, it helps to evaluate the designs of cognitive modeling interface alternatives [17]. Cognitive model is a structure used to predict how users perform before applying it through a system and even before prototyping. It's seen that cognitive modeling plays a more satisfying and supportive role in HCI than people. It can also perceptual, cognitive and motor processes to perform a task. In this process, main goal is to perform the task given with minimum effort or to act like a human and respond to as desired. Another function of cognitive science in HCI is to develop better interfaces for users. While achieving this goal, it can be listed as developing a better interface with the feedback from the predictions, learning time, predicting errors and predicting what should be corrected in the interface according to those predictions.

It can be said that Cognitive Science is used for 3 purposes in HCI. Those;

- Predict human behavior,
- Guiding users in an adaptable model,
- Getting efficiency from other users in group interaction.

2.4. Cognitive Modeling – Advantages and Disadvantages

It's not possible to evaluate individuals as a single group because some differences come to the fore. Likewise, besides the advantages of the systems used in a single group evaluation, some disadvantages may arise. In terms of advantages, cognitive modeling helps interface designers to shape many steps by instructing from early stage of design [18]. It comes to the fore with its applicability easily without spending too much time. Low costing dimension is among factors that make cognitive modeling practical. In addition, this factor also increases effectiveness in the practical use of cognitive modeling. Another advantage of cognitive modeling is to try to answer questions such as how many steps, how long it will take and how much effort it will perform in a human-computer interaction process [14,3]

Cognitive modeling is aimed at finding solutions to problems encountered in different interface designs in cognitive process. Besides producing different advantages, it also has a number of disadvantages. Those disadvantages;

• Focusing on only experienced (constantly performing task) user,
• Insufficient on individual differences,
• Failure to consider user errors,
• Being able to make an estimate about the ideal process.

2.5. Cognitive Modeling Models

Finally, it's also worth noting that cognitive modeling should be shaped according to study to be used in terms of usage. Cognitive modeling put into perspective us a functional feature in making an prediction of task to perform between user and device in a specific time. Different cognitive models have been introduced in HCI and cognitive science. Some of those models listed in below;

• GOMS
• SOAR
• ACT-R
• EPIC
• KLM (Key Stroke Model)
•MHP (Model Human Processor)

2.6. GOMS Model and NYNEX

GOMS model is a feasible model in situations where users are expected to perform the task they have already mastered (performed without errors). Information collected through the GOMS model is used to predict what individual will do in unpredictable situations [19, 20]. In a study conducted according to GOMS model, designer should inform any user whom person wants to test about the goal, method, when/how method should be used. User commands the system, system does so. It tells user what person is doing in single user transactions. In this process, GOMS is user-oriented and performs well in this type. Text graphic editors work well in functions such as page layout creation, spreadsheet creation, User Interface design, WWW, and CAD systems.
It's a comprehensive model and contains mixed items. Indicating choices outlined about objectives in cognitive processes may not always guide HCI researchers. GOMS model has remained very academic and is considered a pioneer in other models, except that it's basic model on HCI.

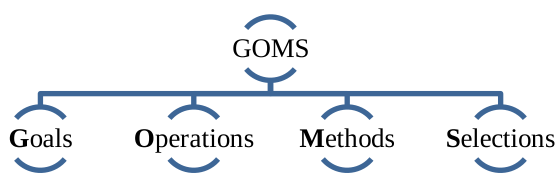


Fig.2. GOMS model and sub-dimensions

1. Goals: Those are tasks given to the user. It can also be described as actions that the design developer asks individual to take.

2. Operations: Actions that software allows the user. Person can perform a task with the mouse or can do it using shortcuts. Here transactions can be defined in this way.

3. Methods: It's way the user chooses while performing given task. Also, user can use different ways according to digital competencies.

4. Selections: If there are different methods of performing a task, user can choose between them. The factor affects here is the situation affecting the selection.

There are some various software are available to facilitate use of model-based evaluation approach. GOMS model is the best known of model-based evaluation methods. One of the best examples of GOMS model is Project Ernestine. Considering that time is equal to money in terms of call center companies, where aim is to conduct interviews, increase in 1-second call time that may occur due to one person in the interviews returns to company as an additional cost. In 1980, a telecommunications company called NYNEX shortened 1-second calling time from each operator and planned to reduce company's annual expenses by $ 3 million. In this respect, an application for shortening calling time will provide the company with a cost advantage. Different opinions have been put forward in this regard and the most effective among the opinions has been to reduce this time by establishing an additional station with new technological devices.
In this process, context of Project Ernestine, structures such as different keyboard layouts, screen layouts and switching procedures were compared to NYNEX company that wanted to establish a new station, and a system was proposed for the system and information about the GOMS model was provided. In the NYNEX project, analysis was performed using a cognitive model according to the GOMS model. As a result of a proposal prepared according to the GOMS model at the end of this process, he also predicted that the new devices planned to be installed will not decrease calling time and will increase those times by 0.69 seconds. If stations that are supposed to be established are not installed, company will not be able to decrease calling times and at the same time, it has been reached that this projected increase will return approximately $ 2 million per year for company.
On this subject, in task analysis prepared according to model applied, company didn't establish a new station, returned from loss and implemented suggestions to be made after making an predict according to it. As mentioned above in this process, cognitive models can be used effectively and actively in every step of design process with little effort and cost.

3. METHOD

3.1. Research Design and Procedure

Participants performed given tasks via smart phones. They were selected according to convenience sampling among participants. Participants were instructed to perform tasks exactly as described to ensure the best comparison between performance and model estimates. In order to make given tasks completely correct and errorless, participants were tested as a result of some instructions. As a result of this experiment, individuals performed their basic tasks. When performing those tasks, it was decided to perform task again from beginning in case of any mistake, and a path was followed accordingly.

3.2. Problem

Problem of research is whether CogTool tool makes a real-like accurate prediction as a result of participants performing tasks in line with some tasks and whether KLM, GOMS and similar cognitive models have an effective effect in practice.

3.3. Participants

The research group consists of 10 people, 4 male and 6 female users, who actively use the Garanti BBVA Bank mobile application. Target audience of the application includes people who have been actively using Garanti BBVA mobile application for a while and made financial transactions using their smart phones. The participants' ages are between 26 and 46 and the average as 31.2 ages. In addition, participants were selected from those who have completed their postgraduate studies and actively work in academy.

3.4. Research Tools

Tests applied during research were made concrete by processing with Excel software in Windows PC. As well, CogTool which is a cognitive modeling tool in order to perform user tests and make predictions, has been the most frequently used software within framework of its study. The usage and general information of the CogTool tool is as follows.

3.5. CogTool and Applications

It's a free software developed by Carnegie Mellon University to measure usability of interfaces based on cognitive modeling and use ACT-R architectures. CogTool is a general-purpose user interface prototyping tool. It automatically evaluates designs with a predictable human performance model. CogTool can be used to base existing interface, compare competitors' interfaces, and predict how good your new designs will be. Psychomotor and cognitive processes help us make an average estimate for experienced users and provide an example of a prediction to those who have developed design interface so that user can take action. It's used to carry out procedures on how long was spent on a required task or what an experienced user is on a task.

Advantages of CogTool;
- Provides feedback in order to develop reusable designs,
- Measure the performance for different designs,
- Gives a chance to make an evaluation against competitors,
- It can be used very beginning to the end of the product development process.

In addition to theory, it enables implementation of cognitive models in practice. Assuming that you are a company owner and need to develop an interface, an experienced user will provide an predict of how long it takes to perform a task on a desired platform, and as a result of this estimate, you might have information about how useful the interface you want to develop. In this way, the CogTool tool has demonstrated its effectiveness in practice and has been actively used to provide users with realistic results. Also, CogTool is a software provides fast and practical results, guessing quantitative data, based on acting as if there is a user without an existing user.

3.6. Tasks

No	Instruction	Difficulty	Steps
1	Finding the IBAN number of personal account	Easy	2
2	Finding current debt of any registered bill	Normal	6
3	Finding current account activity of the personal card for last 1 month	Hard	7

Fig.3. Task, difficulty and steps

Tasks and steps that participants are asked to perform within the scope of our study. While determining tasks, most used features and critical operations that can be performed by using application are taken into consideration in Garanti BBVA mobile application. It has been assigned some tasks related to mobile application of Garanti BBVA. In this process, it's expected to perform tasks with the users logged on. Those tasks and difficulty levels given to participants are listed below and quantitative data of research are detailed below in the Findings section.

4. FINDINGS

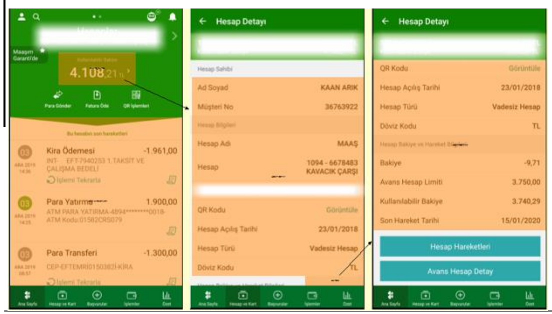
	Mean Time (sec)	User Test Results		CogTool Prediction (sec)	Difference (sec)
		Minimum (sec)	Maximum (sec)		
Task 1	5,54	4,14	6,69	6,1	0,56
Task 2	8,67	7,59	9,45	9,9	1,23
Task 3	11,60	10,62	13,21	12,1	0,50

Fig.4. Participants' time to perform assigned tasks and CogTool predictions.

As seen in Table 1, duration of participants assigned tasks and average time to perform Task 1 is 5.54 sec - the lowest 4.14 sec and the highest is 6.69 sec, Task 2 is 8.67 sec - the lowest 7.5 sec and the highest time was 9.45 sec and average time was 11.60 sec, the lowest was 10.62 sec and the highest was 13.21 sec. Respectively, CogTool prediction for tasks performed were 6.1 sec for Task 1, 9.9 sec for Task 2 and 12.1 sec for Task 3. Accordingly, between real-time experience and CogTool estimates, 0.56 seconds in Task 1, 1.23 seconds in Task 2 and 0.50 in Task 3 were measured. In the light of those data, it's seen CogTool tool predicts life-like results with a small rate of error compared to the average time in assigned tasks. List of tasks assigned to participants is given in Table 2, Table 3 and Table 4 with details.

Task 1: Finding the IBAN number of personal account
1. Finding "Account" tab on Garanti BBVA mobile application.
2. Tap Account number button.
3. Finding IBAN number of personal account.

Fig.5. Participants' time to perform assigned Task 1 and steps.



Task 2: Finding current debt of any registered bill
1. Finding “Transaction” tab on Garanti mobile application.
2. Tap “Payments” button.
3. Tap “Invoice” tab.
4. Selecting “Bill Payment” process.
5. Tap “Registered Bill Payment” button
6. Tap the "Get Bill" button

Fig .6. Participants' time to perform assigned Task 2 and steps.

Task 3: Finding current account activity of the personal card for last 1 month
1. Tap “Account and Card” section.
2. Touching “Accounts” button.
3. Tap on the deposit account.
4. Moving page down and touching "Account Transactions" button.
5. Touching "Last 7 Days" button on the Account Transactions page.
6. Selecting "Last 1 Month" from the pop-up menü.
7. A cursory glance on detailed account.

Fig.7. Participants' time to perform assigned Task 3 and steps.

As seen in Figure 1, users were asked to access and review their account information under Task 1. A button was added to the Accounts section via CogTool, and a review plugin was included in other sections. Steps of cognitive processes were shown in Figure 2.

Fig.8. Participants' follow steps while performing Task 1

Frame	Action	Widget/Device
1	Look At	HEAP HAREKETLERİ (Widget 1)
1	Think for 1.200 s	
1	Move and Tap	BAKİYE_BUTON (Widget 2)
2	Look At	HESAP DETAYI (Widget 1)
2	Move and Tap	BUTON2 (Widget 2)
3	Look At	HESAP-DETAYI2 (Widget 2)
3	Think for 1.200 s	

Fig.9. Steps of prediction for Task 1 with CogTool

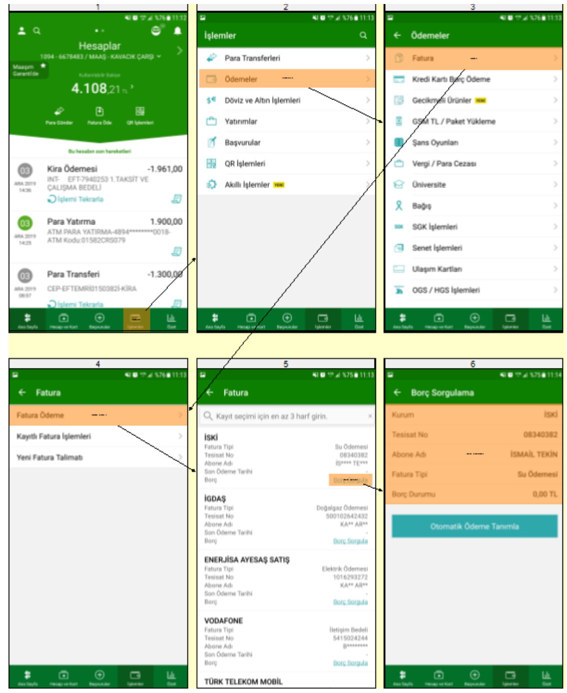


Fig.10. Participants' follow steps while performing Task 2

As seen in Figure 3, users were asked to find the invoice debt registered under Task 2. On the existing screen, initially, "Transactions"→"Payments"→"Invoice"→"Invoice Payment" and "Inquiry" button of the desired invoice was examined to examine the incoming query. Steps of the cognitive processes were shown in Figure 4.

Frame	Action	Widget/Device
1	Think for 1.200 s	
1	Move and Tap	İŞLEMLER (Widget 1)
2	Think for 1.200 s	
2	Move and Tap	ÖDEMELER (Widget 1)
3	Think for 1.200 s	
3	Move and Tap	FATURA (Widget 1)
4	Think for 1.200 s	
4	Move and Tap	FATURA ÖDEME (Widget 1)
5	Think for 1.200 s	
5	Move and Tap	BORÇ SOGULA (Widget 1)
6	Look At	BORÇ ORGULAMA (Widget 1)
6	Think for 1.200 s	

Fig.11. Steps of prediction for Task 2 with CogTool

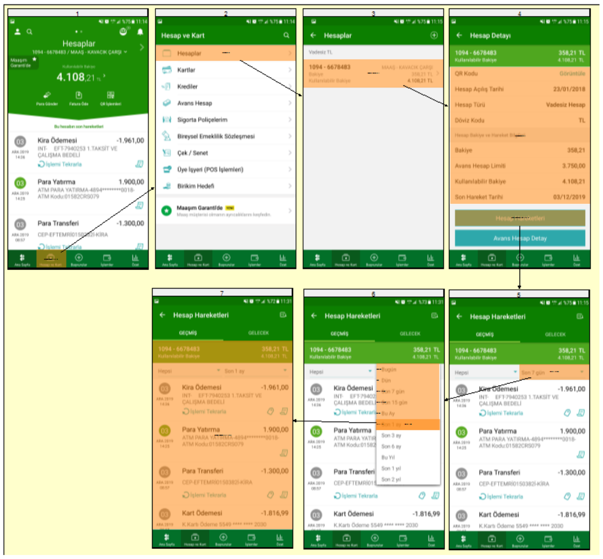


Fig.12. Participants' follow steps while performing Task 3

As seen in Figure 5, users were asked to check and examine the last 1-month account activity within Task 3. In the existing screen, initially, "Accounts" → "Accounts" tab → "Entering the Current Account" → "Opening Account Details" and the "Last 1 Month" button of the desired account, the process of examining the account details was performed. Steps of cognitive processes were shown in Figure 6.

Frame	Action	Widget/Device
1	Think for 1.200 s	
1	Move and Tap	HESAPLARBUTON (Widget 1)
2	Think for 1.200 s	
2	Move and Tap	HESAPLAR (Widget 2)
3	Think for 1.200 s	
3	Move and Tap	VADESİZHESAP1 (Widget 1)
4	Look At	HESAPDETAY1 (Widget 1)
4	Think for 1.200 s	
4	Move and Tap	HEAP HAREKET BUTON (Widget 2)
5	Think for 1.200 s	
5	Move and Tap	SON 7 GÜN (Widget 3)
6	Look At	dÜN (Widget 5)
6	Think for 1.200 s	
6	Move and Tap	SON 1 AY (Widget 10)
7	Look At	HESAP HAREKET 1 AY (Widget 1)
7	Think for 1.200 s	

Fig.13. Steps of prediction for Task 3 with CogTool

As seen in Figure 7, 8, and 9, it's seen that estimated duration of expenditure is visualized for the dimensions created by taking into account made by CogTool. In this section, vision, eye movement realization and preparation, cognitive process and hand movement dimensions are presented in prediction. Amount of time allocated to which size is given below.

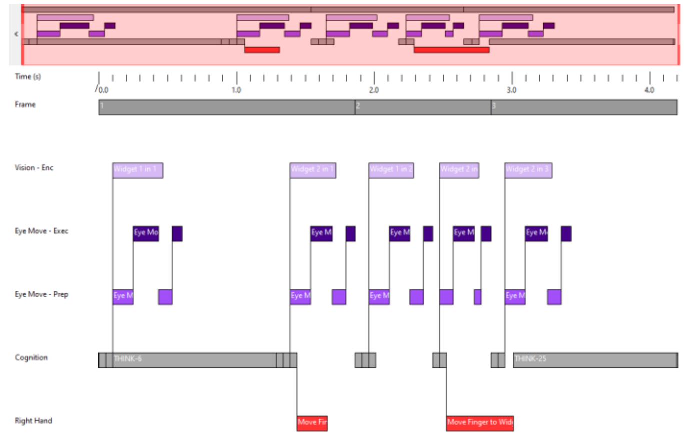


Fig.14. Visualization of CogTool's prediction for Task 1

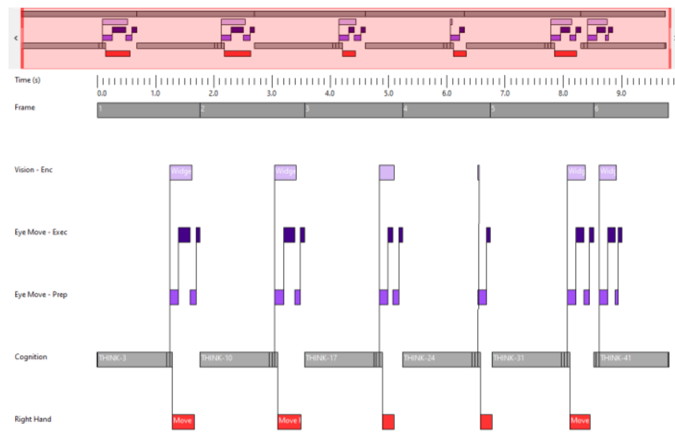


Fig.15. Visualization of CogTool's prediction for Task 2

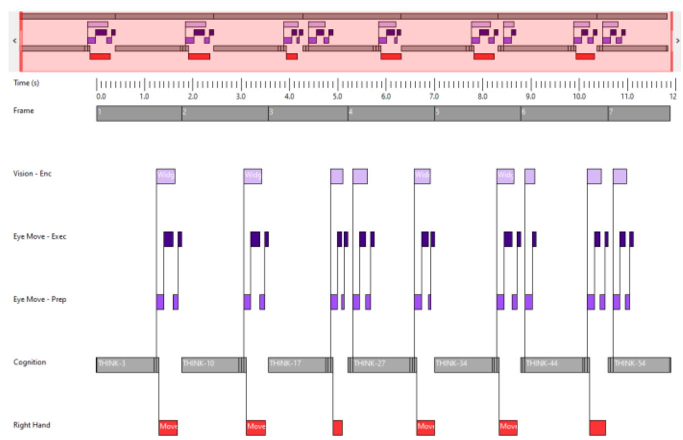


Fig.16. Visualization of CogTool's prediction for Task 3

 ISSN: 2548-0650

5. CONCLUSIONS

CogTool-like tools run a system prediction based on cognitive modeling theories. Aim is to make an inference about how long experienced users can perform a task by conducting a prediction. Academicians concluded experienced users in the field of CogTool and cognitive modeling are a tool that makes close predictions about testing the interface design for usability. [17, 21, 22, 23, 24, 25, 26]. In CogTool predictions, error rate is limited as 20%. Very small rate of error gained more importance as CogTool made lifelike predictions in terms of developing the interface. Likewise, as mentioned above, NYNEX project has been essential for company to take a precaution without applying certain activities, which can be applied to individuals and give efficient results.

On the other hand, while studies conducted with the CogTool tool are available, it's argued that number of scientists working in the same field are not reliable and that the predictions in use for CogTool-like usability are not reliable and do not yield predictive results in use.

In the study of CogTool tool with experienced users by giving certain tasks about certain models, they also concluded that the difference between interface alternatives regarding human performance is not predicted sufficiently and does not give results close to normal and it is not a reliable tool in decision making on KLM, GOMS and CogTool based interface design [27, 28, 29].

In last studies performed in HCI, CogTool has been argued that it makes a close prediction in real-time tasks, and in other studies it has moved away from real-time tasks. However, the number of these articles was found to be low. It has generally been shown to produce realistic results.

REFERENCES

[1] Shneiderman, B. (1980). Software psychology: human factors in computer and information systems. Cambridge, Mass: Winthrop Publishers.
[2] Weinberg, G. M. (1998). The psychology of computer programming (Silver anniversary ed). New York: Dorset House Pub.
[3] Çağıltay, K. (2018). Teoriden Pratiğe İnsan – Bilgisayar Etkileşimi ve Kullanılabilirlik Mühendisliği (2. bs). İstanbul: Seçkin Yayıncılık.
[4] Acartürk, C., & Çağıltay, K. (2006). İnsan bilgisayar etkileşimi ve ODTÜ'de yürütülen çalışmalar. Akademik Bilişim, 6, 9-11.
[5] Çağıltay, K. (1995). Herkes için internet. Ankara: ODTÜ.
[6] Dix, A., Finlay, J., Abowd, G. D., & Beale, R. (2004). Human-computer interaction (3rd ed). Harlow, England ; New York: Pearson/Prentice-Hall.
[7] Dillon, R. F. (1983). Human factors in user-computer interaction: An introduction. Behavior Research Methods & Instrumentation, 15(2), 195-199. https://doi.org/10.3758/BF03203548
[8] Dreyer, J. (1981). The Penguin dictionary of psychology. Harmondsworth: Penguin Books.
[9] Boring, R. L. (2002). Human-Computer Interaction as Cognitive Science. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 46(21), 1767-1771. https://doi.org/10.1177/154193120204602103
[10] Ertürk, E. M. (2017). Bilimsel psikolojinin tarihsel süreci üzerine. Trakya Üniversitesi Edebiyat Fakültesi Dergisi, 7(14), 161-180.
[11] Meister, D. (1999). The history of human factors and ergonomics. Mahwah, N.J: Lawrence Erlbaum Associates.
[12] Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: toward a new foundation for human-computer interaction research. ACM Transactions on Computer-Human Interaction, 7(2), 174-196. https://doi.org/10.1145/353485.353487
[13] Myers, B. A. (1998). A brief history of human-computer interaction technology. interactions, 5(2), 44-54. https://doi.org/10.1145/274430.274436
[14] Card, S. K., Moran, T. P., & Newell, A. (1983). The psychology of human-computer interaction (Reprinted). Boca Raton, Fla. London New York: CRC Press.
[15] Busemeyer, J. R., & Diederich, A. (2010). Cognitive modeling. Los Angeles: Sage Publishing.
[16] Olson, J. R., & Olson, G. M. (1990). The Growth of Cognitive Modeling in Human-Computer Interaction Since GOMS. Human-computer interaction, 5, 221-265.
[17] Gray, W. D., John, B. E., & Atwood, M. E. (1993). Project Ernestine: Validating a GOMS analysis for predicting and explaining real-world task performance. Human-computer interaction, 8(3), 237–309.
[18] Cox, A. L., & Peebles, D. (2008). Cognitive modelling in HCI research. Cambridge University Press.
[19] John, B. E. (1995). Why GOMS? interactions, 2(4), 80–89 https://doi.org/10.1145/225362.225374
[20] Peebles, D., & Banks, A. (2010). Modelling dynamic decision making with the ACT-R cognitive architecture. Journal of Artificial General Intelligence, 2(2), 52-68.
[21] Held, T., & Schrepp, M. (2011). Effective cognitive modeling for business software – Where and how can cognitive models support usability professionals in their everyday work? Proceedings of Usability Professionals Association International Conference Book, 1-12.
[22] John, B. E. (2005). Cognitive Human Performance Modeling by Demonstration. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 49, 1153–1156. SAGE Publications Sage CA: Los Angeles, CA.
[23] John, B. E., & Suzuki, S. (2009). Toward cognitive modeling for predicting usability. International Conference on Human-Computer Interaction, 267–276. Springer.
[24] Luo, L., & John, B. E. (2005). Predicting task execution time on handheld devices using the keystroke-level model. CHI'05 extended abstracts on Human factors in computing systems, 1605–1608. ACM.
[25] Ocak, N., & Cagiltay, K. (2017). Comparison of cognitive modeling and user performance analysis for touch screen mobile interface design. International Journal of Human–Computer Interaction, 33(8), 633–641.
[26] Swearngin, A., Cohen, M. B., John, B. E., & Bellamy, R. K. (2013). Human performance regression testing. Proceedings of the 2013 International Conference on Software Engineering, 152–161. IEEE Press.
[27] Jorritsma, W., Haga, P.-J., Cnossen, F., Dierckx, R. A., Oudkerk, M., & van Ooijen, P. M. (2015). Predicting human performance differences on multiple interface alternatives: KLM, GOMS and CogTool are unreliable. Procedia Manufacturing, 3, 3725–3731.
[28] Lee, J., & Billman, D. (2011). Modeling performance differences across systems, tasks, and strategies. Proceedings of the Annual Meeting of the Cognitive Science Society, 33.
[29] Salvucci, D. D., & Lee, F. J. (2003). Simple cognitive modeling in a complex cognitive architecture. Proceedings of the SIGCHI conference on Human factors in computing systems, 265–272. ACM.

BIOGRAPHY

Kaan Arık obtained his BSc degree in Computer and Instructional Technologies Education from Sakarya University (SAU) in 2015. He received the BSc., and MSc. diploma in Computer and Instructional Technologies Educationfrom the Sakarya University in 2018 and still student of PhD in İstanbul University, Informatics Department. Also, he currently works at the Department of Digital Game Design, Beykoz University. His research areas related with Game Design, Machine Learning, Computer Human Interaction and Deep Learning. He also aims to work in interdisciplinary fields of study.

THE SIGNAL SYSTEM IN BRAIN

D. Dogan

***Abstract*—** The brain is a command centre that controls and regulates the body and mental functions. The brain consists of an average of 100 billion nerve cell networks. These neurons in the brain regulate information communication with the muscles, other nerves and gland cells in the organism. Neurons in the brain provide this information transfer both electrically and chemically. Neurons perform signal communication just like electronic networks in computers. While neurons are similar to other cells in highly structured organisms, they are distinguished from other cells by their unique electrochemical ability to transfer information within milliseconds. Communication network established by neurons provides people to learn, speak, run, eat, drink. This study aims to get to know the brain in general and to give information about the signal system in the brain.

***Keywords*—** *Brain, Nervous System, Neuron, Glia.*

1. INTRODUCTION

THE human body is a whole of different systems in a balanced communication from top to bottom. The central nervous system ensures coordination with each of the different systems in the body. The Central Nervous System (CNS) evaluates impulses from other parts of the body and develops appropriate responses to these impulses. The nervous system consists of two parts, the central and peripheral nervous systems [1].

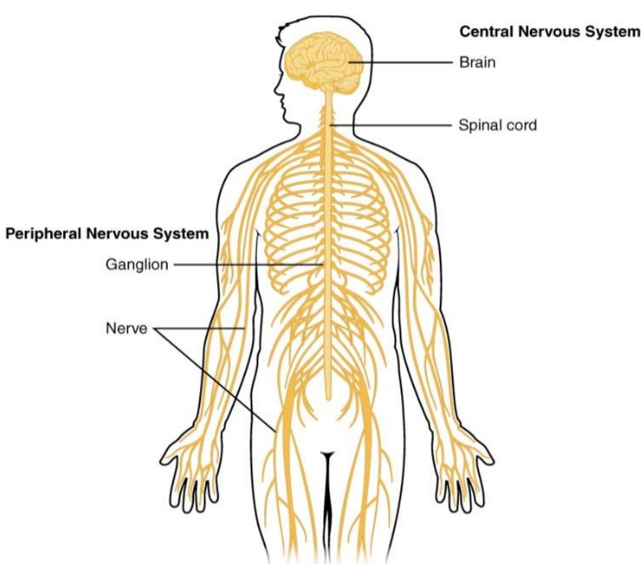


Fig.1 Central and Peripheral Systems [2].

Demet Dogan is with Inonu University, Department of Biology, Malatya, Turkey, (e-mail: demet.dogan@yahoo.com).

Manuscript received Sep. 12, 2019; accepted Oct 21, 2019.
Digital Object Identifier:

The Central Nervous System consists of two parts, the brain and the spinal cord. The brain is the part of the central nervous system inside the skull. The spinal cord is the structure in the spine that connects the brain and the peripheral nervous system and controls the reflexes. Internal and external events are perceived by the sense organs. Sense organs transmit information to the central nervous system with the help of a large number of neural networks in the spinal cord at the back of the brain [1,3].

In addition to being the most important organ in our body, the brain is the organ where we have the least information about its functions. The functions of the regions in the brain are only understood as a result of some arousal and injury in the brain cortex.

2. BRAIN, STRUCTURE AND FUNCTIONING

The brain is the most important and complex part of the central nervous system. It is located in the anterior and upper part of the skull cavity and is present in all vertebrates. Inside the brain, the skull is located in a transparent fluid called spinal fluid, which maintains it both physically and immunologically [1,4]. The function of the brain as part of the CNS is to regulate the majority of body and mind functions. Respiration, heart rate regulation, thinking, talking, etc. all life functions are the task of the CNS.

Although the brain is classified into three parts by scientists: forebrain, midbrain and posterior brain, it is an organ that is more complex and difficult to categorize [3,5]. This complex structure consists of various regions. These regions undertake different tasks. Seeing, hearing, tasting, motion controls, perception and speech are controlled from different parts of the brain.

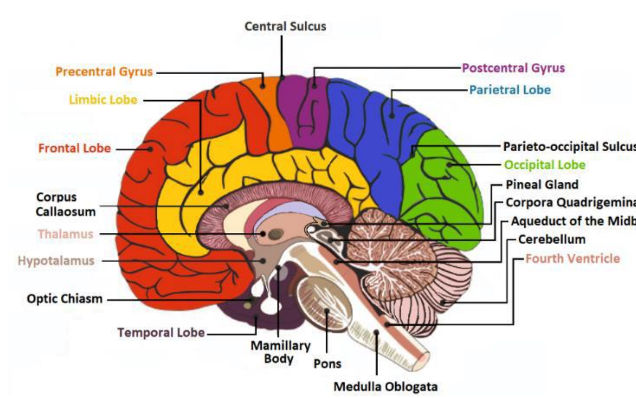


Fig.2 Internal parts of the brain [5].

The cerebellum is located at the back of our heads. The cerebellum helps keep our body in balance. Also, the muscles are compatible with each other. The most basic task of the cerebellum is to provide balance and to evaluate the warnings from the eye [1,6].

The spinal cord is the posterior brain portion located between the spinal cord and the pons. The spinal cord on dandruff, just like in the cerebellum and spinal cord substances are available. The motor nerves in the brain are also distributed diagonally across the spinal cord. The most important tasks of spinal cord bulb; Digestive, respiratory, circulatory and excretory systems to ensure the operation. Also, controlling and regulating the blood sugar of the liver controls vital reflexes such as swallowing, sneezing, coughing and vomiting [3,5].

Brain in humans is one of the most advanced and complex among all animal species. It is not only bigger but also twisted and folded, creating grooves and layers in itself, which gives it a wrinkled appearance. The human brain weighs about 1.5 kilos. The weight of the brain constitutes 2% of the weight of human weight. It has excellent cell management. The human brain is approximately 1.4-1.5 kilos (3.3 lbs), and its volume is approximately 1130 cc in women and 1260 cc in men. The majority is composed of glial cells and neurons [4].

3. Cells of the Brain

The brain consists of two types of cells: neurons and glia cells.

3.1. Neurons

Although neurons generally have different shapes, basically all of them have a cell body, dendrites and axon. Neurons exchange information through electrical and chemical signals in living organisms, just like circuits in computers. Our brain evaluates millions of signals from our body through neurons and compares them with previous information in our memory, selects them, and consequently establishes new connections between neurons [3,7].

There are spaces between the neurons where signal communication and energy transfer are provided, and these spaces are called synapses. Synapses are the main actors of intercellular communication [8,9].

In the structure of a neuron, there are multiple structures called dendrite that first detect the signals from other nerve cells. This multi-armed structure is similar to an antenna that receives radio signals. Signals received through the dendrites are transferred to what is called the cell body. The structure of this part, also called soma cell, contains basic cellular organelles such as cell nucleus, endoplasmic reticulum, ribosome and mitochondria. The main function of Soma cells is the centre where these transmitted signals are controlled, the cell DNA is stored and also the energy required for cell activity is produced and stored. The signals that are decided to be evaluated and transmitted in Soma cells are transferred to the nerve extension called an axon, which resembles an electrical cable. Some axons perform signal transmission within milliseconds, as they are covered with an oily structure called myelin, which increases the speed of information transfer, just like fibre cables used in today's technology [1,3,10].

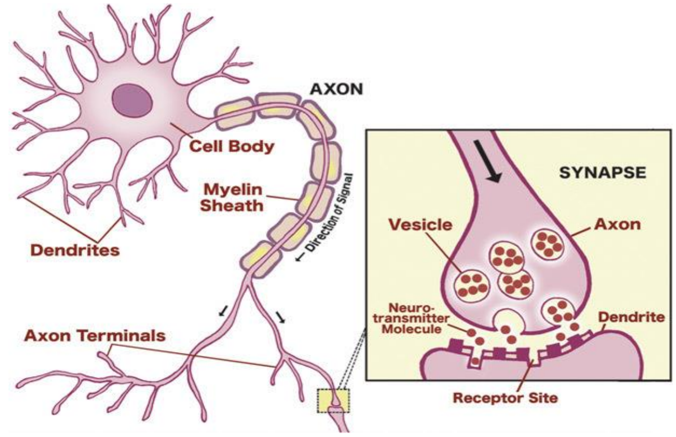


Fig.3. The structure of the nerve cell [11].

As we have already mentioned, signal transmission in nerve cells occurs not only through electrical elements but also through chemical elements. These chemicals are called neurotransmitter substances [10]. Neurotransmitter substances are stored near the synapse region of axons, when this part is stimulated with an action potential, it is released into the synapse cavity and signal communication from one cell to another by binding by receptors in the dendrites of the other recipient cell. Examples of neurotransmitters are dopamine, serotonin, oxytocin, etc. for example [3,9,10].

3.2. Glia cells

Glia cells, which means glue in Greek, are the most abundant cell types in the brain. Glia cells do not play a role in direct electrical signal transmission like neurons, but they act indirectly. By means of these cells, another cell of the brain is protected, fed, and the axons are coated with myelin, which accelerates the signal transmission of neurons [12,13].

Basically, as a result of the numerous scientific studies conducted with the above-mentioned tasks in the brain, it has been understood that it is more active in brain functional function. There are many types of glia cells in the nervous system. Microglia, for example, protect the brain against invading invaders and remove any debris that has formed. Oligodendrogilia synthesizes the myelin, which provides the rapid transmission of electrical messages. Astrocytes allow the connection of molecules and nutrients to neurons in the functioning of the blood-brain barrier. They control the protection of the damaged area, neuronal defence, and repair of damage against effects caused by external influences in the brain [1,3,12,14].

4. Conclusion

The working system of the brain is based on neurons and communication between them. As the number of information (stimulants) from the external environment increases, the number of connections between neurons continues to increase rapidly. Thus, with this communication network between neurons, it enables people to walk, run, hear, see and use their memory effectively.

 ISSN: 2548-0650 http://dergipark.gov.tr/jcs

REFERENCES

[1] J. K. Mai, G. Paxinos, *The Human Nervous System*, Third Edition, 2012, USA.

[2] https://qbi.uq.edu.au/brain/brain-anatomy/peripheral-nervous-system, Access: October 2019.

[3] P. Brodal, *The Central Nervous System: Structure and Function*, Third Edition, 2004, New York, USA.

[4] https://www.cognifit.com/tr/brain, Access: May 2018.

[5] http://www.yenibiyoloji.com/beyin-yapisi-ozellikleri-beynin-bolumleri-ve-kisimlari-1605/, Access: June 2018.

[6] E. R. Kandel, J. H. Schwartz, T. M. Jessell, *Principles of neural science*. New York: McGraw-Hill, 2000.

[7] Z. Li, M. Sheng, "Some assembly required: the development of neuronal synapses," *Nature Reviews*, Vol.4, pp.833-841, 2003.

[8] G.M. Shepherd, Ch.1: "Introduction to Synaptic Circuits". *The Synaptic Organization of the Brain*. Oxford University Press US. 2004.

[9] I.B. Levitan, L.K. Kaczmarek, The Neuron: cell and molecular biology, Fourth edition, 2015, New York, USA.

[10] R. Carter, S. Aldridge, M. Page, S. Parker, *The Human Brain Book*, *New York*, NY: DK Publishing, 2009.

[11] http://www.educarer.org/brain.htm. 2006.

[12] N. Baumann, D. Pham-Dinh, *Biology of Oligodendrocyte and Myelin in the Mammalian Central Nervous System*, Physiological Reviews, Vol. 81, No. 2, 2001.

[13] R.D. Fields, B. Stevens-Graham, *New Insights into Neuron-Glia Communication*, Science, 2002, Vol.298, No.5593, pp. 556-562.

[14] W. F. Ganong, *Excitable tissue: Nerve*, In Review of medical physiology, Singapore: McGraw Hill, 2005, pp.51–60.

BIOGRAPHIES

Demet Doğan graduated from Inonu University department of Biology, Malatya-Turkey. She received the PhD degree in Biology from Inonu University in 2014. Her current research interests are molecular biology, biosystems, biomechanics, and bioengineering.

ARTIFICIAL INTELLIGENCE AND DEEP LEARNING METHODOLOGIES

B. Alafi

Abstract— In this paper, a brief definition and history of Artificial Intelligence and deep learning are mentioned. The procedure from Artificial intelligence to deep learning is described. Due to human loss and disabilities in complicated problems and huge data amount, Artificial Intelligence and learning methods were introduced. Their main aim is to make machines perform like humans. These two – Artificial Intelligence and Deep Learning – are not separated from each other, but their application is different. As a sequence, the main concept of the algorithm for each one is announced and compared. In the end, all remarks on Artificial Intelligence and Deep learning are discussed.

Keywords— *Artificial Intelligence, Deep learning, AI, Learning system.*

1. INTRODUCTION

THE words Artificial Intelligence was first used in 1956, and has become very popular due to advanced algorithms such as increased data volumes, advances in computing power and storage AI. due to human disability in facing with some computing and storage issues. This topic was welcomed by defense agencies for some topics like problem-solving, symbolic methods, mapping projects. As a result, the first individual assistant was introduced during the first street mapping project in 1970. While in Hollywood films including, Transformers AI is depicted as human-like robots that take over the world [1,2]. The latest evolution of AI technology, however, is neither that frightening nor that wise. Alternatively, AI has benefited from various sectors, including modern examples such as healthcare, banking, fashion, education, and more. AI's main goal is to give machines human intelligence. This focuses specifically on making the machines smarter and thinking as well as behaving like humans. These machines are being trained for problem-solving and thinking better than humans do. The best examples of AI are self-driving cars and robots [5,6]. Regarding the mentioned topics, Machine Learning is an AI sub-set which focuses exclusively on making predictions based on experiences. It allows the machine to make a decision based on knowledge and data rather than an explicit program to perform a specific task. The algorithms are specifically designed to learn and improve over time and help the user make a better choice [5]. Machine Learning is divided to three types: supervised, unsupervised, and reinforcement or semi-supervised learning [7]. Different issues especially on data subject – analyze data, Collect data, Filter data, Train algorithms, Test algorithms, Use algorithms for future predictions – are dealt with Machine Learning; image recognition can be mentioned as an example for applying these methodologies. At last, Deep Learning is one of Machine Learning techniques that is recognized via neural networks and inspired by brain neurons performance. Deep neural networks which are inspired by the human brain's function are used by a collection of the task-specific algorithm as a neural network. The main inspiration of deep learning is by neuroscience which is affected by ongoing knowledge, observing, experience, tentative discovering. The classification of deep learning can be identified by patterns that provide expected output and result for a received input. Deep learning as an approach of machine learning is associated by machine learning but not interchangeable with limitations of it. At a far glance of these subjects, it is observed that deep learning is located inside the machine learning, and machine learning is located inside the Artificial intelligence, on the other word artificial intelligence is overarching all learning algorithms.

Behnaz Alafi. is with Electrical Engineering Faculty Istanbul Technical University, Istanbul, Turkey, (e-mail: alafi18@itu.edu.tr).

Manuscript received Sept 09, 2019; accepted Jul 11, 2019.
Digital Object Identifier:

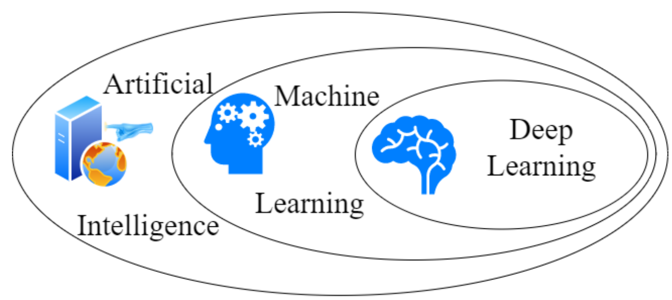


Fig.1. AI, Machine Learning, and Deep Learning interconnection

2. GENERAL CONCEPT OF ARTIFICIAL INTELLIGENCE(AI)

Artificial Intelligence is a branch of computer science that tries to copy or simulate human intelligence on a machine, so machines can often perform tasks that require human brain and abilities and totally intelligence. planning, learning, reasoning, problem-solving and decision making are considered as some programmable functions of AI systems. Algorithms via techniques like machine learning, deep learning, and relevant rules support Artificial intelligence systems. Learning and especially machine learning algorithms feed data to Artificial Intelligence systems and train them through statistical techniques. Machine learning helps AI systems to act better without the need for special planning.

2.1. KNOWLEDGE-BASED SYSTEM

A knowledge-based system is a kind of Artificial Intelligence system with the aim of capturing knowledge and experiences from human for problem-solving and decision making. Human learning, thinking, decision-making, and action are supported by knowledge-based techniques for a knowledge-based system.

Knowledge-based system is one type of Artificial Intelligent systems that its aim is taking human knowledge and expert to be trained. The quality of this kind of cooperating with human is related to aforesaid training process. So, utilized learning techniques and algorithms are important factor in knowledge-based systems.

2.2. Machine learning

Machine learning is a technique which can support an Artificial Intelligent system to be trained without being programmed directly and clearly. Before the invention of learning algorithms, it was necessary to program the system clearly. It was very hard for complicated duties and systems and did not apply to all type of functions. By the way, learning techniques have been used for supporting systems by capturing knowledge and experiences and use them for training themselves. Machine learning uses computer programming to take data as its feed and use them for learning itself without human intervention. A machine learning algorithm is divided into two main categories: supervised, and unsupervised [6].

2.3. Fuzzy logic

Creation of Intelligent machines, and the effect of computer logic on creating these machines, influence their logic and make difficult to imitate the human behavior. To achieve the purpose of learning human behavior and imitate the way of human thinking the fuzzy theories and logic were created. In 1965, the first research paper about fuzzy sets was published by Lotfi A.Zadeh. fuzzy logic deals with real information which is uncertain, unclear, implicit, and without plain boundaries. On the other words, fuzzy logic is located in contrast to Boolean logic, it is considered as many-valued logic and involving any real number between 0 and 1 both inclusive. This kind of theories and logic provides a reasonable means for better analyze of objects. All fuzzy logic-based computational algorithms have been used in the construction of the intelligent system, and development of decision-making, control process, optimization, and pattern and image recognition [2].

3. Deep learning algorithm(DLA)

Deep learning is a sub-part of the machine learning technique [5]. Since it can learn from an enormous amount of unstructured and unlabeled data – known as big data – under the unsupervised category, is known as a deep neural network or deep neural learning. Today, because of the data explosion from each area in the world that is called big data, deep learning has completed gradually in response to this data explosion. Gathering and processing of big data that is related to alternative sources in the world would take the human being a lot of times maybe decades. This vast amount of unstructured and unlabeled data is learned by deep learning. A brilliant example of deep learning implementation is on detection of fraud or money laundry. Deep learning consists of multiple simple technologies. Improvement of these technologies eventually developed deep learning. The most known algorithms of deep learning are the convolutional neural network (CNN), recurrent neural network (RNN), denoising autoencoder (DAE), deep belief networks (DBNs), long short-term memory (LSTM) [6-9]. CNN is one of the most popular models of deep learning which is introduced by details in following sections as an instance.

3.1. Mathematical description

As aforesaid, deep learning is a subset of machine learning which executes machine learning process via utilizing organized artificial neural networks and inspired by the structure of the human brain. In terms of deep learning this structure called an artificial neural network (ANN). Since artificial neural networks are structured like a human brain consisting connected set of nodes similar to brain neurons, the human thinking way that can be learnt and mimicked by machines via a deep learning algorithm. Because of this hierarchical neural network structure of deep learning approach, the process of data can be carried out through a nonlinear approach. When some input data is fed to a neural network, process via layers of the perceptron to produce the desired output is done. The mathematical structure of the deep learning includes linear algebra, probability and information theory (stochastic models), and numerical computations. In mathematical structure of a neural network, data of one pattern set as the input set in entered to a set of nodes via some factors named weights which are selected randomly, then the output of these nodes which are called hidden layer is given to the activation function, and the output of these activation function box will be the network output. The architecture of a node in the neural network is represented as figure2 [8].

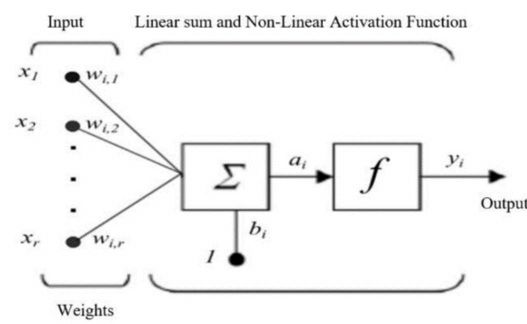


Fig. 2. Neural network Node Architecture

There are two steps for training in all models of deep learning and also in CNN, feed-forward step and back-propagation step. In deep learning, the learning procedure is done by updating the weight values. Backpropagation or "backward propagation of errors" is introduced for solving the problem of updating the weights and training multiple neural networks or deep neural networks [9]. In the backpropagation algorithm, the errors are passed to hidden layers to train the network. If the error does not reach the hidden layers, weight cannot be adjusted. So there would be no point if they were not trained. The training problem can be solved by the activation function. The calculation procedure in deep neural networks is as follow:

Step1- initialize the weight

Step2- calculate the error (can be specified as the mean squared error (MSE)), e stands for error.

$$e = \frac{1}{N} \times \sum_{i=1}^{N} [t_i - o_i]^2 \quad (1)$$

Step3- adjust the weight values to reduce the error, w stands for weight.

$$w(n) = -\eta \frac{\partial e}{\partial w} + \alpha w(n-1) \quad (2)$$

$$\Delta w = -\eta \frac{\partial e}{\partial w} \quad (3)$$

Error is the difference between the correct output and network output. The weight adjustment is done based on the error. Convolution is a mathematical operation as follow:

$$x[n] * h[n] = \sum_{k=-\infty}^{+\infty} x[n-k].h[k] = \sum_{k=-\infty}^{+\infty} x[n].h[n-k] \quad (4)$$

$$(x * h)(t) = \int_{-\infty}^{+\infty} f(\tau)g(t-\tau)d\tau = \int_0^t f(\tau)g(t-\tau)d\tau \quad (5)$$

In a CNN, for an arbitrary input an arbitrary filter is used to perform this convolution operation. The performance of this filter is represented as figure3.

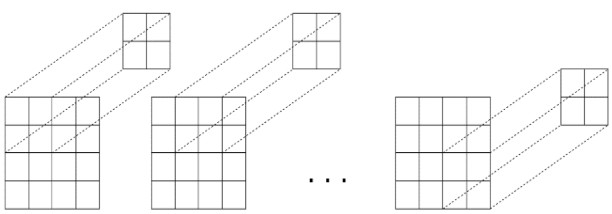


Fig.3. Convolution operation in CNN

During convolution performance, the input is scanned by filter according to its dimension. In other words, the filter is going to convolve across each filter. the CNN consists of three main layers: convolutional layer, pooling layer, and fully connected layer respectively. convolutional layer receives input then transforms the input in some way and then output the transformed input in the next layer. During the pooling layer, a function commonly based on the maximum operation is applied over a portion of the input to create an output. Out of pooling layer is smaller than the input dimensionally. Behind the convolution and pooling layer, there is another layer named fully connected layer which has a neural network construction and features and representations that are learned from data through Convolutional and pooling layer are fed to this fully connected neural network without hand engineering them like the event that is happened in machine learning. one or multiple convolutions and pooling layer can be in a CNN. In other words, the output of the pooling layer is the input of the future artificial neural network. Structure of a CNN is represented as figure4.

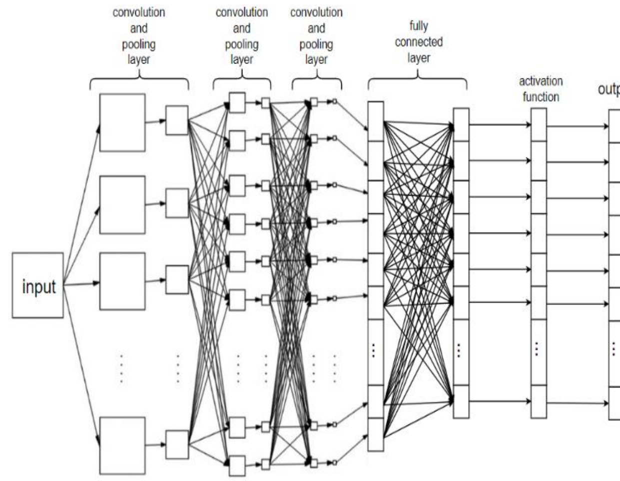


Fig.4. CNN architecture

In a CNN, the gradient descent is the mathematical facts that help to find the best filters, convolutions, pooling layers, fully connected layers etc. It starts with random values for everything such as filters, convolution layers, then it checks the lots of errors and then uses the gradient descent to move in a direction to reach a few errors. And this gradient descent is used in the back-propagation stage.

3.2. FLOW CHART

Deep neural network is an extension of neural network that contains two or more networks. The model of the deep neural network is represented as figure5.

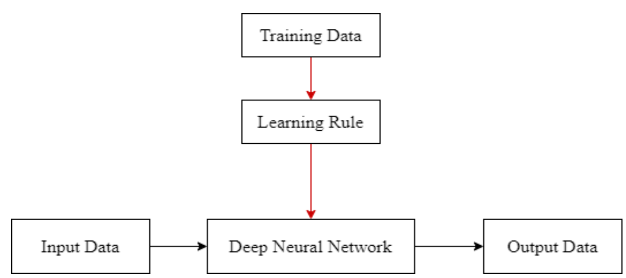


Fig.5. Deep neural network training model

The training data train the network using learning rules. Once the network is trained, the input data is provided and the network generates output data. In neural networks all data is stored in weights, so for training the network with new information, the weight values should be modified. The systematic way of modifying the weight values is called “Learning Rule”. Descent gradient is utilizing to update the weight values in back-propagation stage. Back-propagation stage is executed to reduce the error value and reach the best result as output in Deep learning. The use of back-propagation as the crucial part of deep learning algorithm is represented as figure 6.

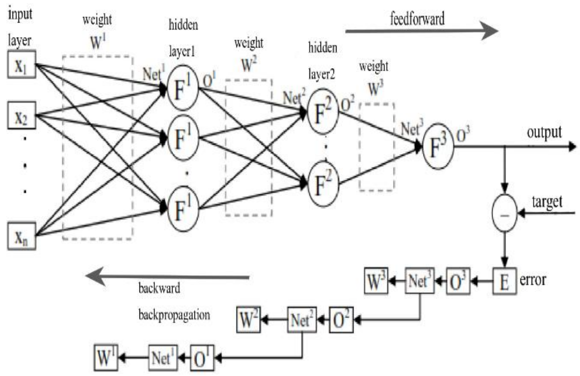


Fig.6. BP process

In CNN which consists three main layers, first of all, the input is convolved by the filters, then it crosses the pooling layer to be smaller than input in dimension, convolution and pooling layers are three-dimensional layers and one CNN may have multiple convolutions and pooling layers. Then the output of the last pooling layer is flattened. The output of pooling layer is 3D feature map, but the input of fully connected layer is 1D feature vector. Flattening turns the 3D output of pooling layer into 1D input of fully connected layer. After this process, the learning process is completed and learned data is entered to a neural network and finally, the output is obtained as it is shown in figure4. The flowchart of CNN is represented as figure7.

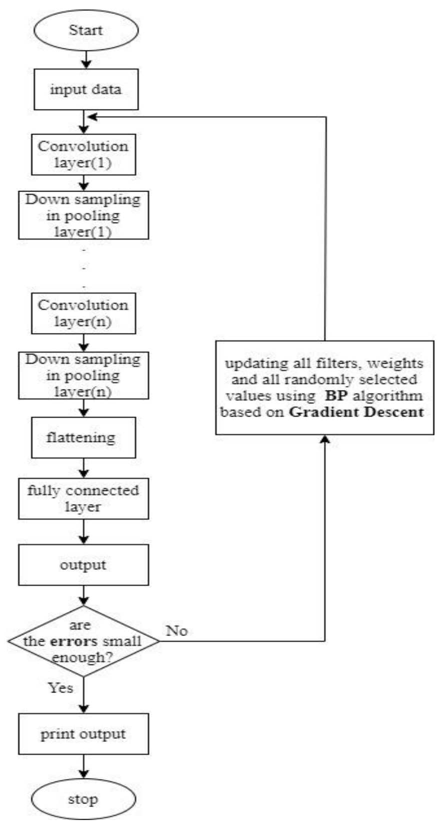


Fig.7. CNN flowchart

4. Comparisons on the AI-Algorithm using DLA

The meaning of AI is to enable the machine to think and act like a human and that is the main target of as an AI system like self-driving cars, robots etc. machine learning is a subset of AI systems that makes that system to be AI. And it provides statistical tools to explore and analyze the data. Machine learning is divided into three categories: supervised, unsupervised, and reinforcement. The role of deep learning as a subset of machine learning is determining the learning procedure by mimicking the human brain. The main idea behind deep learning is imitating the human brain in the learning process and has an architecture like the human brain that is called multi neural network architecture. Deep learning has various techniques inside of itself. Finally, being AI is considered as a goal that deep learning helps to reach this aim.

5. Concluding Remarks and Discussions

According to above discussion, it can be stated that an artificial neural network is a functional unit of deep learning; deep learnings uses artificial neural networks which mimic the behaviour of the human brain to solve complex data-driven problems. Now deep learning in itself is a part of machine learning which folds under the larger umbrella of artificial intelligence. Artificial intelligence, machine learning, and deep learning are interconnected field. Machine learning and deep learning aids artificial intelligence by providing a set of algorithms and neural networks to solve data-driven problems. Deep learning makes use of artificial neural networks that behave similarly to the neural networks in our brain. Since deep learning has the ability to analyze big data and modelling the human brain using neural networks to more effectively realize how the human brain works, it has a specific position in cognitive systems and provides cognition for a system.

Acknowledgement

Thanks to members of Istanbul Technical University, Cognitive System Laboratory.

References

[1] Pierson, P.E, Lillian. Data Science For Dummies, John Wiley & Sons, Inc, 2015.

[2] *Relationship of artificial intelligence, machine learning and deep learning: 101*. (n.d.). Academia.edu - Share research. https://www.academia.edu/39460436/Relationship_of_Artificial_Intelligence_Machine_Learning_and_Deep_Learning_101

[3] D. H. Tolley, (Mapelton, UT, US) 2007 Method of operating a plant and a control system for controlling the same United States GBI Structures, L.L.C. (Springville, UT, US) 7206772.

[4] H.D. Wehle, (2017). Machine Learning, Deep Learning, and AI: What's the Difference?.

[5] H. D. Wehle, (2019). Artificial Intelligence. 10.13140/RG.2.2.28657.74089.

[6] T. Mitchell, (1997). Machine Learning. McGraw Hill. p. 2. ISBN 978-0-07-042807-2.

[7] *CIS 419/519 applied machine learning - Spring 2020*. (n.d.). Penn Engineering | Inventing the Future. https://www.seas.upenn.edu/~cis519

[8] B. Alafi, "A New Cognitive System Modeling with the Combination of Expert and Neural Network Systems". *The Journal of Cognitive Systems*, Vol.3, No.2, 2018, pp.34-35.

[9] Goodfellow-et-al-2016, Deep Learning, Ian Goodfellow and Yoshua Bengio and Aaron Courville, MIT Press, url{http://www.deeplearningbook.org, 2016

[10] H. Schulz, S. Behnke, "Deep Learning". *KI-Künstliche Intelligenz*, Vol.26, No.4, 2012, pp.357–363.

[11] A. Mosavi, S. F. Ardabili, A.R. Varkonyi-Koczy, "List of Deep Learning Models," 2019, (doi: 10.20944/preprints201908.0152.v1)

BIOGRAPHIES

Behnaz Alafi obtained her BSc. degree in electrical engineering from Iran University of Science and Technology(IUST) in 2009, Tehran, Iran. MSc. Student at Istanbul Technical University. She has experience in electrical systems of oil and gas, petrochemical, and energy industry since 2009.

ELECTRICAL PROPERTIES OF THE NEURON AND ELECTRICAL MODELLING OF PASSIVE NEURON CELL MEMBRAN

M.F. Beyazyuz

Abstract**—** Neurons are linked to each other and other cells through an electrochemical mechanism. Understanding the electrical properties of neurons is essential for understanding the functioning of the brain. We can model the single neuron by standard electric circuits, and these models could be used for modeling of neuron networks. And modeling of neural networks is important for understanding the whole brain. Although we can model a single neuron by electric circuits, there is a difference between them in terms of the nature of electric charge carriers. While the main charge carrier is electrons in standard electrical circuits, neurons have a different mechanism. The main charge carriers in neurons is ions. The cell membrane is an insulator and there are some specific channels on it with different permeability for different ions. This structure of the cell membrane is very important for signal transmission in neurons. Passive modeling of the cell membrane is the basis of signal transduction in neurons.

Keywords**—***Neuron, Passive Cell Membrane, Electrical Modeling, Electrical Properties*.

1. INTRODUCTION

NEURONS interact with each other and other cells in the body with electrochemical pulses. They form neural networks that create the control and decision mechanism of the organism. Each neuron can create thousands of connections with other neurons. At a typical brain, there are about 100 trillion synapses. Also, a typical neuron fires 5 - 50 times per second [1]. It is very difficult to understand the functioning of such a complex structure. To model this large and complex structure, passive neurons must first be understood. In this article, the electrical membrane model will be examined in case the membrane potential is below the threshold value. This model provides a basis for modeling the action potential that plays an important role in cell communication and then modeling neuronal networks that interact with each other. For this, the physical properties of neurons will be examined first. Then the structures that enable signal transmission in neurons and their electrical properties will be examined.

2. LITERATURE REVIEW

To model neural networks, the physiology of a single neuron must be well understood. In this way, neuron networks will be better understood. Many models examine the electrical structure of neurons passively or actively. One of the most famous models that model the functioning of the neuron is The Hodgkin – Huxley model. This model examines the structure of the passive membrane and the propagation mechanism of the action potential. *Morris-Lecar Model* is another successful model that can model the active properties of the neuron. The feature of these two models is that they are models containing single neurons. In this study, the physiology of the neuron will be examined and a simple electrical modeling of the membrane will be made for the passive neuron [1-4].

3. PHYSIOLOGY OF NEURONS

A typical human neuron can be examined in three main sections as dendrite, axon, and soma. The cell body of the neuron, the soma, is about 20 μm in diameter and contains most of the organelles such as the nucleus, mitochondria, endoplasmic reticulum, ribosomes, and other organelles. At the cell body, the cell produces ATP, packs the neurotransmitters, contains genetic material and combines cell proteins [3]. Dendrites take impulses which are excitatory or inhibitory from other cells and transfer them to the cell body. Axon is a long nerve fiber that transmits a signal from the cell body to another nerve cell or muscle cell. Axons have various lengths and diameters. Mammal axons are usually around 1 to 20 μm in diameter, and some of them can reach 1 m in length. Some axons can be covered with an insulating layer called the myelin sheath. The myelin sheath is not continuous but is divided into sections separated by Ranvier nodes at regular intervals [1,3,4].

The place where the dendrite of one neuron interacts with the axon of another neuron is called the synapse. Each neuron has an average of 1,000 synapses, but this number can vary greatly [2]. The information goes unidirectionally from the axon side called as pre-synaptic terminal to the dendrite side called the post-synaptic terminal. There is a gap called the synaptic cleft between the terminals which is approximately 10 - 50 nm [3]. Neurotransmitters are specialized molecules packed in vesicles in soma, carried by the legs kinesin to the end of the presynaptic axon and released into the synaptic cleft to reach the post-synapse and excite or inhibit an electrical impulse to the receiver neuron, that process is the reason of unidirectionally signal flow through the pre-synapse terminal to the post-synapse terminal [3].

The cell membrane is about 7.5 to 10.0 mm in diameter and covers the entire cell. The main content of the cell membrane is phosphoglycerates, consisting of glycerides and phosphoric acid. This molecule consists of two main parts, the head of the molecule consists of phosphoric acid, which is hydrophilic, the molecule's tail consists of hydrophobic hydrocarbon chains. These molecules are arranged so that their hydrophilic portions face out [3].

Muhammed Furkan Beyazyüz is with Electrical Engineering Faculty Istanbul Technical University, Istanbul, Turkey, (e-mail: beyazyuz@itu.edu.tr).

Manuscript received Sept 12, 2019; accepted Nov 20, 2019.

4. IONS AS CHARGE CARRIERS

Although the electrical properties in the neuron are very similar to the standard electrical circuit properties, there is a difference between them. The current flowing through the axon is carried out by ions, not electrons, and voltages are potential differences created by gradients in ionic concentrations.

There are two kinds of forces that affect the ions, one is the electrostatic force and the other is the diffusion force. Diffusion force is related to membrane permeability, the electrostatic force is related to interactions of charged particles. There is a kind of balance between the intracellular and extracellular ions in the passive neuron. This balance can be examined by the Nernst equation, which is using for single ions [1,2,5]. The Nernst equation is shown Eq.1. [2, 4].

$$V_{in} - V_{out} = \frac{RT}{zF} ln \frac{[X]_{in}}{[X]_{out}} \quad (1)$$

V_{in} = Intracellular voltage
V_{out} = Extracellular voltage
R = The ideal gas constant
T = The temperature in Kelvin
z = The valence of the ion
F = Faraday's constant
$[X]_{in}$ = Intracellular concentration of the ion
$[X]_{out}$ = Extracellular concentration of the ion

Goldman-Hodgkin-Katz equation is an expanded version of Nernst equation; this equation only gives the relationship between multiple ions. The Goldman-Hodgkin-Katz equation is shown below; [2, 4].

$$V_{in} - V_{out} = \frac{RT}{F} ln \frac{P_K[K^+]_{in} + P_{Na}[Na^+]_{in} + P_{Cl}[Cl^-]_{in}}{P_K[K^+]_{out} + P_{Na}[Na^+]_{out} + P_{Cl}[Cl^-]_{out}} \quad (2)$$

V_{in} = Intracellular voltage
V_{out} = Extracellular voltage
R = The ideal gas constant
T = The temperature in Kelvin
F = Faraday's constant
P_X = Permeability of each of the three ionic species
$[X]_{in}$ = Intracellular concentration of each ion
$[X]_{out}$ = Extracellular concentration of each ion

Intracellular fluid consists of an aqueous solution containing more dense potassium than extracellular fluid, but less dense chloride, sodium, calcium, and magnesium, also in the intercellular fluid, there are some organic anions which cannot leave the cell. Ions are the main factor that determines the electrical properties of neurons. There are some disadvantages to carrying electricity with ions, but they are vital for many activities of the brain. Ions transmit signals much slower compared to electrons because it is very difficult to move ions. However, the diversity in ions provides important capabilities for signal transmission [5,6].

5. ELECTRICAL PROPERTIES OF NEURONS

The cell membrane is the main structure responsible for receiving information from the cell's environment as an interface between inside the cell and outside the cell. The movement of ions in and out of the cell forms the basis of the electrical transmission of a signal [7].

There is a current that flows across the membrane called transmembrane current. Transmembrane current is the sum of the capacitive current, the ionic current, the synaptic current, and the stimulus current. The capacitive current is a result of the natural capacitance of the cell membrane. The ionic flux, the primary membrane current, can be the sum of currents of different ion types. When a synapse is activated by neurotransmitter released from presynaptic terminals, synaptic currents are generated. And the stimulus current is an external current applied to the membrane. The transmembrane current equation 3 is shown below [3,8].

$$I_m = I_{cm} + I_{ion} + I_{syn} - I_{stim} \quad (3)$$

I_m = The transmembrane current
I_{cm} = The capacitive current
I_{ion} = The ionic current
I_{syn} = The synaptic current
I_{stim} = The stimulus current

The cell membrane consists of a double-layer lipid layer and, at rest, there is a potential difference between the two sides of the membrane, as a result of which the cell membrane has a capacity value. Membrane capacitance can be calculated with the following equation 4 [2].

$$C_m = \frac{k\varepsilon_0}{d} \quad (4)$$

C_m = The membrane capacitance
k = The dielectric constant of the insulator
ε_0 = The permeability of free space
d = The membrane thickness

Structures that are hollow proteins with pores in their middle and that allow ions to flow into or out of the cell are called ion channels. Channel proteins work like holes in the cell membrane. Most of the electrical properties of cells and tissues are formed by the movement of ions through these channels. Because of that, there is a voltage difference between intracellular and extracellular, called transmembrane potential. When cells not in transmission, transmembrane potential is about -60 mV, that value known as resting membrane voltage [3,4,9].

$$V_m = V_{in} - V_{out} \quad (5)$$

V_m = Transmembrane potential
V_{in} = Intracellular voltage
V_{out} = Extracellular voltage

Any positive change in membrane potential is called depolarization, negative change is called repolarization If the membrane tension is below the resting membrane tension, it is called hyperpolarized. If the intracellular potential difference rises above a certain value which is called the threshold as a result of excitations from dendrites, this triggers the action potential flowing through axons [3,9].

6. THE ACTION POTENTIAL

The nerve axon acts as a very weak electrical conductor because the axoplasm, the cell fluid inside the axon, has a very high resistance. If we compare the resistances of a squid axon with copper wire of the same diameter, the resistance for the squid axon is 30 to 60 ohms-cm, while the copper wire is 1.8 x 10^{-6} ohms-cm, which means 107 times more voltage drop in the axon than copper wire [2].

The signals are carried over axons and transported from the synapse of the sending cell to the dendrites of other cells. The electrical resistance of axons is extremely high. Therefore, the signal is transmitted by a different mechanism. Action potential plays an important role in this transmission mechanism. It has a characteristic structure based on an all-or-nothing basis [10].

The action potential occurs in five stages as rising phase, peak phase, falling phase, sub-phase and refractory period. With the stimuli collected from the dendrites, some stimulating or inhibiting changes occur in the intracellular voltage value. These stimuli can come from receptor cells or other neurons. If the threshold value is exceeded as a result of these voltage-gated changes, the permeability of the voltage-gated Na^+ ion channels increases. The membrane potential becomes more positive as a result of the Na^+ ions entering, which also increases the permeability of the voltage-gated Na^+ channels so more Na^+ ions entering into the cell. However, this increase in membrane potential is short-lived, because, after a while, the voltage-gated Na^+ channels close and depolarization stops, this is called the peak phase. Following this, voltage-gated K^+ ion channels are opened and K^+ ions come out of the cell; thus, the membrane potential becomes more negative. After a while, the membrane potential temporary becomes under the resting membrane potential because the permeability of the voltage-transition K^+ ion channels is high. After a while, the permeability of the voltage-gated K^+ ion channels become a normal value, so the action potential ends [5,9,11].

The capacitance value of the cell membrane affects the time required to reach the threshold value because the amount of charge required to reach a certain potential is related to the capacitance. If the capacitance is high, the transmission speed decreases, if it is low, the speed increases. Resistance also affects the time it takes to reach the threshold value, so the speed also depends on the resistance of the environment inside and outside the membrane. In small resistances, the time required to reach the threshold value decreases [4,12] .

Myelinated axons produce nerve impulses that spread from one node to another in Ranvier nodes, this type of propagation is called saltatory transmission. Membrane capacitance per length of myelinated axon is higher than the unmyelinated axon, which increases the transmission rate. The resistance of the axoplasm depends on the axon diameter since there is no change in the axon diameter, the transmission rate increases in the myelinated axons [4,11].

7. EQUIVALENT CIRCUIT OF PASSIVE CELL MEMBRANE

The electrical behavior of the cell membrane can be modeled in terms of electrical circuits. The electrical circuit that models the cell membrane is called the equivalent circuit model. The circuit consists of three components, resistors, batteries, and capacitors. Resistors represent ion channels, batteries represent concentration gradients of ions, capacities represent the charge storage ability of the membrane. Stimulations that exceed the threshold create changes in the permeability of the ion channels. Since the permeability of the ion channels that could be modeled with a linear electrical resistance in the active membrane will change over time, they cannot be modeled with linear resistance elements. Modeling can be done using linear resistors for a passive cell membrane [5,10,12,13]. The modeling of passive neuron membrane is shown below. There is a voltage difference of approximately -60 V between the inside and the outside.

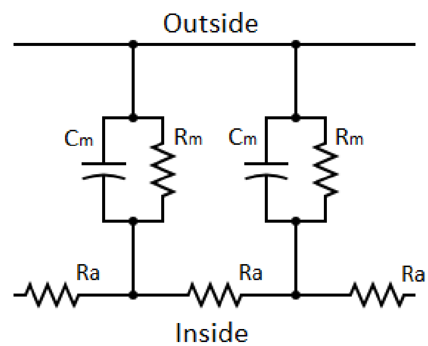


Fig.1. Electrical Modeling of Passive Membrane

R_m= Membrane resistance
R_a= Axial resistance
C_m= Membrane capacitance

Also, different ion channels could be determined in terms of different resistance elements. In this situation, the electrical analogy of passive cell membrane gets better. This model is shown below [2, 4].

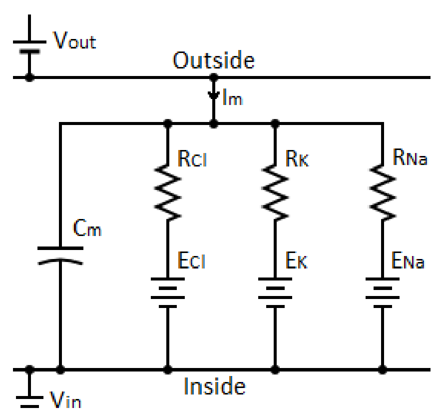


Fig.2. Electrical Modeling of Passive Membrane with Different Ion Channels

The following equations could be found by using electrical modeling of the passive membrane with different ion channels circuit. The capacitance current equal to the sum of the ionic currents and the current source [2,4].

$$V_m = V_{in} - V_{out}$$

$$C_m \frac{dV_m}{dt} = -\frac{V_m - E_{Cl}}{R_{Cl}} - \frac{V_m - E_K}{R_K} - \frac{V_m - E_{Na}}{R_{Na}} \tag{6}$$

I_m = Total transmembrane current
V_{out} = Intracellular voltage
V_{in} = Extracellular voltage
R_{Cl} = Reactance of single Cl^- ion channel
R_K = Reactance of single K^+ ion channel
R_{Na} = Reactance of single Na^+ ion channel
E_{Cl} = Cl^- Nernst potential
E_K = K^+ Nernst potential
E_{Na} = Na^+ Nernst potential
C_m= Membrane capacitance

8. CONCLUSION

As a result, it is important to know the electrochemical properties of neurons to understand neuron networks and the whole brain because neurons interact with each other and other cells with electrochemical mechanisms. An electrical model can be used to simplify signal transmission between neurons, a complex process involving ions and organic machines. An electrical model can be used to simplify signal transmission between neurons, a complex process involving ions and organic machines. In this way, neuron networks can be modeled and the functioning of the brain can be understood more easily. The examination of the electrical model of the passive state neuron is required for modeling the active neuron. The passive neuron cell can be modeled with linear circuit elements.

REFERENCES

[1] J. Zhang, "Basic Neural Units of the Brain: Neurons, Synapses and Action Potential," pp. 1–38, 2019.
[2] B. Ermentrout and D. Terman, "Foundations of Mathematical Neuroscience," p. 440, 2008, doi: 10.1007/978-0-387-87708-2.
[3] J. V. Tranquillo, *Quantitative neurophysiology*, vol.21. 2008.
[4] J. Malmivuo and R. Plonsey, "Bioelectromagnetism Principles and Applications of Bioelectric," *Oxford Univ. Press*, p. 512, 1995. J. Malmivuo,
[5] P. E. Greenwood, L. M. Ward, Stochastic Neuron Models. 2016.
[6] S. Alexander, A. Mathie, J. Peters, ION CHANNELS: Ion Channels, Vol.164, no. supplement s1. 2011.
[7] R. A. Gatenby, "The role of cell membrane information reception, processing, and communication in the structure and function of multicellular tissue," *Int. J. Mol. Sci.*, vol. 20, no. 15, 2019, doi: 10.3390/ijms20153609.
[8] A. Destexhe, Z. F. Mainen, and T. J. Sejnowski, "Synaptic Currents, Neuromodulation and Kinetic Models," *Handb. Brain Theory Neural Networks*, pp. 1–14, 1995.
[9] B. Eisenberg, "Ionic channels in biological membranes - Electrostatic analysis of a natural nanotube," *Contemp. Phys.*, vol. 39, no. 6, pp. 447–466, 1998, doi: 10.1080/001075198181775.
[10] R. Brette, "Theory of action potentials," *Theory of Action Potentials*, vol. 6, pp. 1–48, 2018
[11] M. Fluidity, N. Impulses, and T. A. Receptor, "The Structure and Function of the Plasma Membrane 4.1," pp. 120–171, 2007.
[12] Bard Ermentrout, G., *Methematical Foundations of Neuroscience*. 1990.
[13] I. N. Sabir, J. A. Usher-Smith, "Electrical Properties of Cells," *A Think. Approach to Physiol.*, pp.1–36, 2008, doi: 10.1142/9789812832887_0001.
[14] approach," presented at the Evolutionary Computation (CEC), 2010 IEEE Congress on, Barcelona 2010.

BIOGRAPHIES

Muhammed Furkan Beyazyüz is student of Electrical Engineering at Istanbul Technical University, Turkey.

THE JOURNAL OF
COGNITIVE SYSTEMS

an international, peer-reviewed
indexed, and open-access periodical

PUBLICATION ETHICS

All who participate in producing The Journal of Cognitive Systems conduct themselves as authors, reviewers, editors, and publishers in accord with the highest level of professional ethics and standards. Plagiarism or self-plagiarism constitutes unethical scientific behaviour, and is never acceptable. By submitting a manuscript to this journal, each author explicitly confirms that the manuscript meets the highest ethical standards for authors and co-authors. The undersigned hereby assign(s) to The Journal of Cognitive Systems (JCS) copyright ownership in the above paper, effective if and when the paper is accepted for publication by JCS, and to the extent transferable under applicable national law. This assignment gives JCS the right to register copyright to the paper in its name as claimant, and to publish the paper via any print or electronic medium.

Authors, or their employers, in the case of works made for hire, retain the following rights.

+ all proprietary rights other than copyright, including patent rights
+ the right to make and distribute copies of the Paper for internal purposes
+ the right to use the material for lecture or classroom purposes
+ the right to prepare derivative publications based on the Paper, including books or book chapters, journal papers, and magazine articles, provided that publication of a derivative work occurs subsequent to the official date of publication by JCS.
+ the right to post an author-prepared version or an official version (preferred version) of the published paper on an internal or external server controlled exclusively by the author/employer, provided that (a) such posting is non-commercial in nature, and the paper is made available to users without charge; (b) a copyright notice and full citation appear with the paper, and (c) a link to JCS's official online version of the abstract is provided using the Document Object Identifier (DOI) link

THE JOURNAL OF
COGNITIVE SYSTEMS

an international, peer-reviewed, indexed, and
open-access periodical

VOLUME 04, NUMBER 02

DECEMBER 2019

CONTENTS

www.dergipark.gov.tr/jcs

ISSN 2548-0650