Jurnal Teknologi

Full Paper

COGNITIVE FUNCTION ASSESSMENT IN YOUNG ADULT USING TRAIL MAKING AND STROOP TESTS

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Article history
Received
30 October 2015
Received in revised form
7 March 2016
Accepted
28 March 2016

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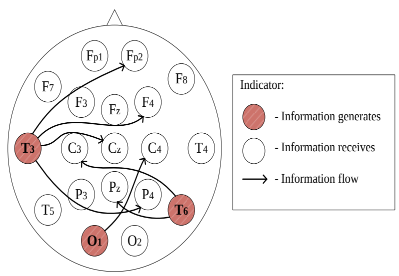
Graphical abstract



Abstract

Cortical network between brain regions is one of the topics that being investigated by brain researchers. Methods that are used to investigate brain developments of cognitive function include Partial Directed Coherence (PDC) and the power spectrum of the brain activity. The purposes of this study were to determine the cortico-cortical functional connectivity between brain regions using PDC and to investigate the power spectrum of brain activity while performing cognitive function assessments. Twenty healthy young adults, age between 20 to 30 years old, were asked to perform two tasks/tests; Trail Making Test (TMTA-alphabet, TMTA-number, TMTB-mixed alphabets and numerical) and Stroop Task. An electroencephalogram (EEG) machine was used to record the brain signals, and the data were analyzed using PDC and Fast Fourier Transform (FFT).Our findings showed that not only frontal area but temporal and occipital area also generates information and the information was sent to various scalp location. Theta frequency was significantly increased at frontal area while gamma and high-gamma frequency bands were significantly increased at centro-parieto-occipito-temporal regions. All of these areas are associated with cognitive function doing specific task.

Keywords: Cognitive function, functional connectivity, partial directed coherence, power spectral density

Abstrak

Jaringan korteks di antara bahagian otak merupakan kajian penting di kalangan para penyelidik otak. Perkembangan otak pada fungsi kognitif dikaji termasuk spektrum kuasa otak. Tujuan kajian adalah untuk menentukan keterkaitan fungsi kortikal-kortikal antara bahagian otak menggunakan *Partial Directed Coherence (PDC)*, dan mengkaji spektrum kuasa aktiviti otak ketika menjalankan ujian fungsi kognitif. Dua puluh orang dewasa yang sihat diikendalikan untuk melakukan dua tugas; *Trail Making Test (TMTA-alphabet, TMTA-number, dan TMTB)* dan *Stroop Task*. Mesin *electroencephalography (EEG)* digunakan untuk merekodkan isyarat otak dan data dianalisis menggunakan *PDC* dan *Fast Fourier Transform (FFT)*. Keputusan menunjukkan majoriti maklumat untuk kedua-dua ujian berasal dari bahagian *frontal* dan *temporal*, dan beberapa maklumat melibatkan bahagian *occipital*. Tambahan pula, maklumat di hantar kepada semua bahagian-bahagian otak. Jalur *theta* telah meningkat naik di bahagian *frontal* semasa kedua-dua ujian dijalankan. Sebagai kesimpulan, fungsi kognitif bukan sahaja berlaku di kawasan frontal tetapi ia mungkin berlaku di bahagian otak lain mengikut fungsi mereka tersendiri.

Kata kunci: Fungsi kognitif, keterkaitan fungsi, *partial directed coherence*, kepadatan spektrum kuasa

1.0 INTRODUCTION

Cognitive function is one of the cognitive processes that enable people to manage and complete routine tasks and activities in life. These activities involve paying attention and responding to solve a problem (shifting task), maintaining focus on a task (inhibition task), and flexibility adjusting planning and organizing to a new priority (shifting task) [1–3]. Cognitive function has been generally studied among researchers as it can enhance human skill and also help determine cognitive disabilities[4–6].

There are several assessments that can be conducted in order to perform cognitive function. Trail Making Test is one of the assessments which has been used in neuropsychology field in identifying cognitive flexibility of a person in their motor speed and focusing in shifting task [7, 8]. Another task that involved in cognitive function is Stroop Task; which is one of the main executive function in inhibiting voluntarily in surroundings [9].

The functional connectivity of cortical networks is characterized by the information networks between distant brain regions during brain activity, and is usually studied using Electroencephalography (EEG), Magneto-encephalography (MEG) [10], Positron Emission Tomography (PET) [11], and Functional Magnetic Resonance Imaging (fMRI) [12]. To estimate the functional connectivity of information flow through various brain regions, directional connectivity techniques based on parametric modeling measures such as Granger causality (GC), directed transfer function (DTF), and partial directed coherence (PDC) [13, 14] can be used. All measurement methods have their advantages and disadvantages, and several papers have used PDC as their directional connectivity measure as it can detect less non-causal connections and had the highest sensitivity for connections in simulations of EEG signal[15–17].

Currently, power spectrums have been practically studied in the cognitive field for searching the function of various brain rhythms. There are six frequency bands of brain rhythm; delta, δ (0.5-4 Hz), theta, θ (4-8 Hz), alpha, α (8-12 Hz), beta, β (12-38 Hz), gamma, γ (38-42 Hz), and high-gamma, hγ (42-120 Hz).

In the present studies, we aimed to discover the connection between cortical networks when performing cognitive function task by using PDC method. In addition, we furthered our studies by identifying the power spectrum of brain rhythm when completing executive function assessments.

2.0 EXPERIMENTAL

2.1 Participants

There were twenty healthy participants that took part in the studies (15 females and 5 males). The range of ages was between 20 to 30 years old. All participants needed to take their meals before the assessments started.

2.2 EEG Recordings

The EEG signals were recorded with EEG machine (Nihon Kohden). 19-channels of electrode cap, in accordance with the International 10-20 System, was applied to participants' scalp in order to capture the brain's activity (i.e.: Fp_1, Fp_2, F_3, F_4, C_3, C_4, P_3, P_4, O_1, O_2, F_7, F_8, T_3, T_4, T_5, T_6, F_Z, C_Z, and P_Z).Another two electrodes disk of silver/silver chloride (Ag/AgCl) were attached at the earlobes of participant as references (i.e.: A_1 and A_2). The 19-channels and the references are illustrated as in Figure 1. The bandpass values were set between 0.05 Hz – 120 Hz and the impedance values was kept below 20kΩ.

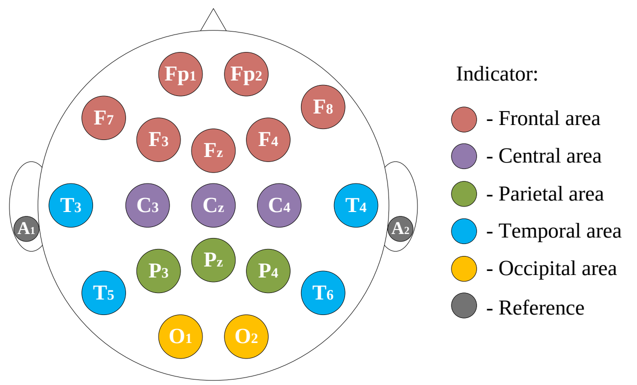


Figure 1 10-20 Electrode placement system with A_1 and A_2references

2.3 Procedures

Each participant was given two conditions to perform, i.e. Control State and Task State. In Control State, participants need to relax their mind for 60 seconds while their brain activity was recorded. Then, they would continue to do Task State that contains two tasks; Trail Making Test (TMT) and Stroop Tasks (ST). Each task was repeated 5 times, and was completed on different day in order to observe the different way of thinking between the tasks.

In TMT task, there would be another three sub-tasks for participants to accomplish; TMTA-alphabet, TMTA-number, and TMTB-mixed alphabets and numerical (TMTB-num&al). This TMT task required participants to trail 25 encircled number and alphabet; depends on the sub-task instruction, from starting point until the end point using pencil. For both TMTA-alphabet and TMTA-number, participants were required to make a series of ascending alphabet or number, while for TMTB-num&al, they need to make an alternating series of number and alphabet. In all TMT sub-tasks, participants were instructed to complete the trail correctly with no specific end time.

Meanwhile for ST task, it required every participant to answer the colour of the word instead of the name that was written in colour word. There were six colours appeared randomly with congruent and incongruent colour. Every participant need to accomplish the task with 30 trials and each trial must be answered within 2 seconds. The task was done using online website: http://cognitivefun.net/.

2.4 Partial Directed Coherence

The information flows between brain activities can be determined by using PDC method. PDC is a frequency domain of Multivariate Autoregressive (MVAR) models that represent from the concept of Granger Causality (GC), which interprets the relative strength of bi-directional structure interaction between multiple channels of EEG signal [18,19].

The PDC equation is derived from the MVAR model as in equation (1);

$$X(n) = \sum_{r=1}^{p} A_r X(n-r) + \xi(n) \tag{1}$$

where A_r is the estimation of $M \times M$coefficient matrix, a_{ij}; which represent the relationship of time series between present value, $x_i = x_i(n)$ is depending linearly on the past value, $x_j = x_j(n-r)$, and $\xi(n)$ is a Gaussian white noise of M-dimension. The p model order is based from the Akaike information criterion; $p = 3$.

Thus, from the Fourier transform of MVAR model, $\bar{A}(f)$ as in equation (2);

$$\bar{A}(f) = I - \sum_{r=1}^{p} A_r e^{-i2\pi fn} \tag{2}$$

where I is the M-dimensional identity matrix. PDC equation can be concluded as in equation (3) with the condition set as in equation (4).

$$\pi_{ij}(f) = \frac{|\bar{A}_{ij}(f)|}{\sqrt{|\bar{A}_{1j}(f)|^2 + |\bar{A}_{2j}(f)|^2}} \tag{3}$$

$$\bar{A}_{ij}(f) = \begin{cases} 1 - \sum_{r=1}^{p} A_{ij}(r) e^{-i2\pi r} & , i = j \\ -\sum_{r=1}^{p} A_{ij}(r) e^{-i2\pi r} & , otherwise \end{cases} \tag{4}$$

The result from PDC method would depicted 19×19 matrix graph as in Figure 2. The x-axis represents the 19-channels of cortical networks that generate information while y-axis represents the cortical networks that receive the information. The information flows between channels of EEG signals were determined by selecting the value of 0.4 and above from the matrix graph as in Figure 3.

2.5 Power Spectrum

The spectral power in six different frequency bands was determined by analyzing the EEG signal using Fast Fourier Transform (FFT).

Then, each normalization of frequency bands was analyzed and statistical analysis using paired two-tailed t-test was performed between Control and Task State with significant difference below than 0.05($p < 0.05$). T-test is used to look for a difference in means of two sample populations. Two-tailed was used to find increased or decreased frequency band in the EEG signal and paired condition was used because of the "repeated measure" performed.

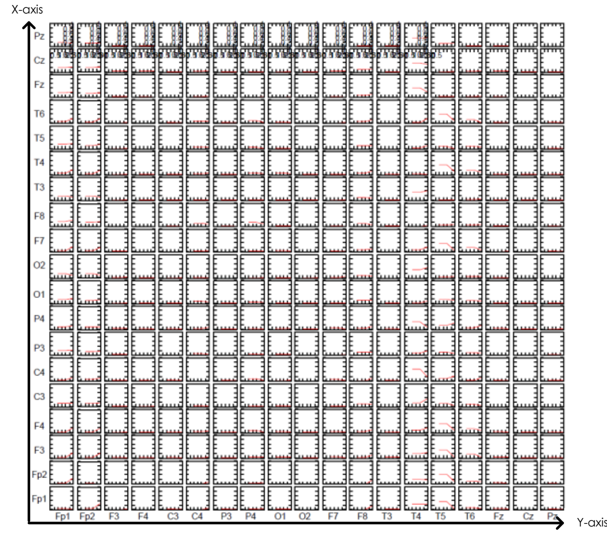


Figure 2 19×19 EEG channels matrix graph

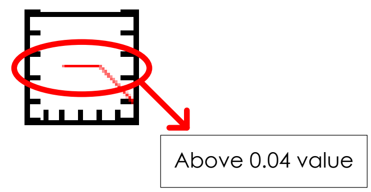


Figure 3 Indicator for information flows from x-axis toy-axis

Then the transformed data were normalized as in equation (5).

$$Normalization = \frac{\sum freq.band}{\sum each\ freq.bands} \times 100 \tag{5}$$

3.0 RESULTS AND DISCUSSION

In Trail Making Test and Stroop Task, each task and sub-task was repeatedfive (5) times to complete the task (In total, $20\ participants \times 5\ trials = 100\ trials$).

3.1 Functional Connectivity

The first objective of this paper was to identify the functional connectivity of brain region while doing cognitive function task. An example (from one of the participant) for directions of information flow between 19-channels in brain region is as illustrated in Figure 4. There were location (shaded circle) that generated information when doing the task, and the information was sent to other location as depicted by location at the end of the arrow to receive the information. The information generated and information received was investigated for all 19 scalp location for each task.

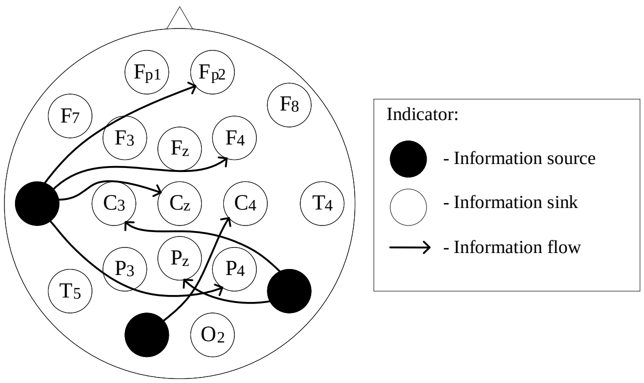
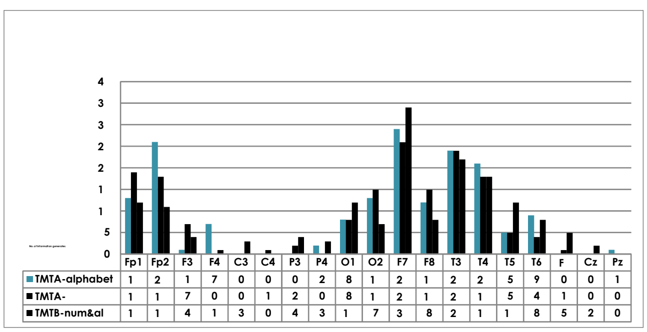


Figure 4 Functional connectivity between brain regions

Figure 5 shows the scalp location/channel for generated information in Trail Making Test. Overall, the highest number of channels that generated the information was at F_7 channel. For TMTA-alphabet and TMTA-number, the brain areas that generated the instruction were mostly at frontal;Fp_1, Fp_2, F_7, and F_8, temporal; T_3, T_4, T_5, and T_6, and occipital area; O_1 and O_2 . Meanwhile in TMTB-num&al, the generated information were distributed over various brain areas; frontal (i.e.: Fp_1, Fp_2, F_3, F_4, F_7, F_8, and F_Z), temporal (i.e.: T_3, T_4, T_5, and T_6), occipital (i.e.: O_1 and O_2), parietal (i.e.: P_3 and P_4), and central area (i.e.: C_3 and C_Z).

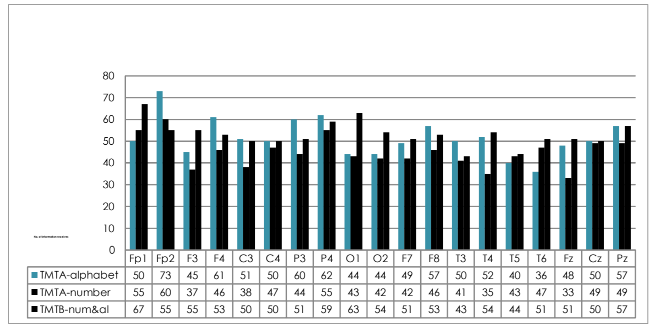


	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	F	Cz	Pz
TMTA-alphabet	1	2	1	7	0	0	0	2	8	1	2	1	2	2	5	9	0	0	1
TMTA-	1	1	7	0	0	1	2	0	8	1	2	1	2	1	5	4	1	0	0
TMTB-num&al	1	1	4	1	3	0	4	3	1	7	3	8	2	1	1	8	5	2	0

Figure 5 Scalp location that generates information during TMTA-alphabet, TMTA-number, and TMTB-num & al sub-tasks and its rate

Figure 6 shows the scalp location that received the information from the source. For all TMT subtasks, the information had been sent to all brain areas but they might differ in occurrence rate according to the task given. More than 50 out of 100 trials in TMTA-alphabet and TMTA-number had frontal; Fp_1, Fp_2, F_4, and F_8, parietal; P_3 and P_4 ,brain location as the information sink. For TMTB-num&al, half of the trials of these receiving channels (information sink), were mostly at fronto-parieto-occipital areas.

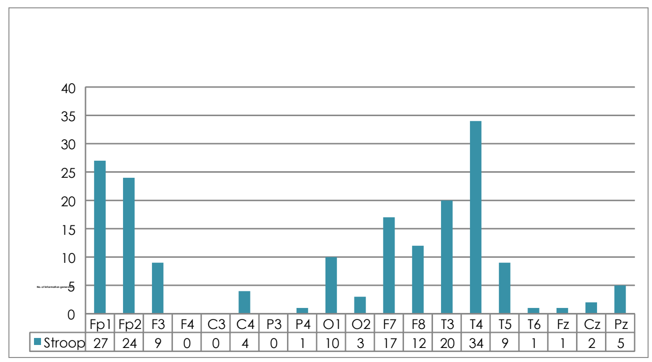
Figure 7 shows the number of information generated channels for Stroop Task. As shown in the figure, the channel that generates information most frequently was at T_4(right temporal area).



	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
TMTA-alphabet	50	73	45	61	51	50	60	62	44	44	49	57	50	52	40	36	48	50	57
TMTA-number	55	60	37	46	38	47	44	55	43	42	42	46	41	35	43	47	33	49	49
TMTB-num&al	67	55	55	53	50	50	51	59	63	54	51	53	43	54	44	51	51	50	57

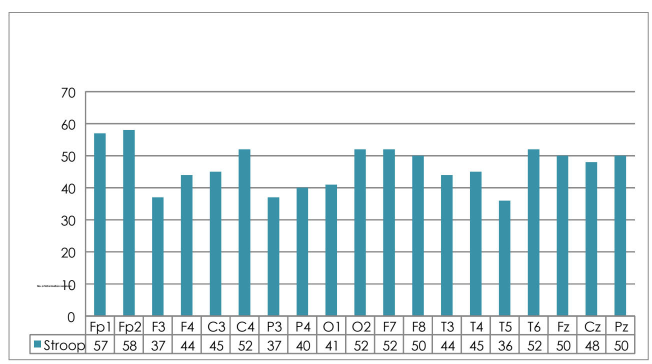
Figure 6 Scalp location that receives generated information during TMTA-alphabet, TMTA-number, and TMTB-num & al sub-tasks and its rate

Meanwhile, Figure 8 shows the number of information receiving channels in the task. The highest number that had information been sent to was at$Fp_1$and Fp_2 scalp location/channels.



	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
Stroop	27	24	9	0	0	4	0	1	10	3	17	12	20	34	9	1	1	2	5

Figure 7 Scalp location that generates information during Stroop Task and its rate



	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
Stroop	57	58	37	44	45	52	37	40	41	52	52	50	44	45	36	52	50	48	50

Figure 8 Scalp location that receives the generated information during Stroop Task and its rate

3.2 Power Spectrum

The second objective of the paper was to discover the spectral power of the brain rhythm for these cognitive tasks. The frequency bands in the Control State and Task State were statistically analyzed based on paired t-test analysis with significant differences of $*p < 0.05$, $**p < 0.01$, and $***p < 0.001$.Only results with significant difference are illustrated in Figure 9 and 10 for Trail Making Test and Stroop Task, respectively.

Overall, the theta, gamma, and high-gamma frequency bands in both Trail Making Test and Stroop Task were significantly increased when compared to Control State. (i.e.: Control θ, γ, $\mathrm{h}\gamma$< Task θ, γ, $\mathrm{h}\gamma$).In contrast, the delta and alpha frequency bands were significantly decreased in TMT of Task State (i.e.: Control δ, α> Task δ, α) when compared to Control State, and only alpha band was significantly reduced in ST of Task State (i.e.: Control α> Task α).

Figure 9 depicts the frequency bands of Trail Making Test with three sub-tasks; (a) TMTA-alphabet, (b) TMTA-number, and (c) TMTB-num&al (number & alphabet) that were significantly increased/decreased when compared to Control State. Based on Figure 9(a), the increased/decreased of these frequency bands was found atcentro-parieto-occipito-temporal regions. The increased theta-band can be seen at several location of frontal area; i.e.Fp_2, F_3, F_4, and F_Z, and at T_6location. Meanwhile, the decreased of delta-band was discovered at the occipital area and $C_Z$location. For the second sub-task; TMTA-number as illustrated in Figure 9(b), the theta-band significantly increased in various location; i.e. Fp_1 , Fp_2 , F_3 , F_4 , F_7 , F_Z , and T_4.Meanwhile for TMTB-num&al sub-task as shown in Figure 9(c), theta-band had significantly increased at frontal and parietal area of the brain. The significantly decreased/increased of alpha, gamma, and high-gamma frequency bands can be found mostly atoccipito-parieto-temporal areas.

Meanwhile, Figure 10 shows the frequency band analysis for Stroop Task. Delta, theta, gamma, and high-gamma frequency bands were significantly increased in Task State when compared to Control State. The opposite was found for alpha frequency bands. The increment and decrement of theta and alpha frequency bands were found at almost all brain area while increment of gamma and high-gamma frequency bands were found mostly at occipital, parietal, and temporal area and right side of frontal (F_3, F_4, F_8, andF_Z) and central area (C_4 andC_Z).

3.3 Discussions

Findings of functional connectivity in Trail Making Test and Stroop Task show that frontal, temporal, and occipital area were where the most generated information location were found during cognitive function assessments. The frontal area, which is associated with cognitive function, plays a role in solving problems, focusing on a solution, and attempting to inhibit any outside interference [20,21]. Meanwhile, the temporal area is well-known as a site of working memory, memory encoding, and involving language performance [22,23].For occipital area, it is significant with the ability of recognizing from visualization, and colour perception [24].

In Trail Making Test, TMTA is relevant for processing speed since the task only need to trail alphabet/number only, while TMTB is significant with cognitive flexibility; which participant needs to alternately trail number and alphabet in sequencing order [25]. Hence, the number of information generated from frontal, temporal, and some other regions might differ in each participant due to their employed thinking process. Meanwhile in Stroop Task, the attention and focuses of a person to exhibit the word of the colour instead the colour itself makes participant used their cognitive ability and working memory to perform the task [9,11]. However, occipital area is also involve in generating the information as TMT and ST tasks need a person to visualize the information given, then process the information and pass the information to other brain region [26].

For the frequency analysis of brain rhythm, the findings from both tasks indicate that theta, gamma, and high-gamma frequency bands were significantly increased when participants perform both tasks. The significant increasing of theta frequency band was typically found at the frontal area.

Theta frequency band is related to memory performance, and also memory encoding and retrieval[27]. Hence, it is proven that one of the important parts of cognitive function; attention and recall memory, is perform at the frontal area[28]. In Finnigan report paper, it stated that executive performances are corresponding with theta frequency band in healthy adulthood [29].Gamma and high-gamma frequency bands are also related to cognitive function in attention on visualization [30]. In the paper of Mizuhara and Yamaguchi, they discovered that gamma frequency band is required in paying attention to an object in order to send information [31].

4.0 CONCLUSION

This study focuses on functional connectivity and power spectra during Trail Making test and Stroop test to investigate cognitive function performance in young adults. Our findings show that not only frontal area but temporal and occipital area also generates information and the information is send to various scalp location. Theta frequency activity increases at frontal area while gamma and high-gamma frequency bands activity increases at centro-parieto-occipito-temporal regions. All of these areas are associated with cognitive function doing specific task. Our functional connectivity and power spectra analyses are compatible with previous findings.

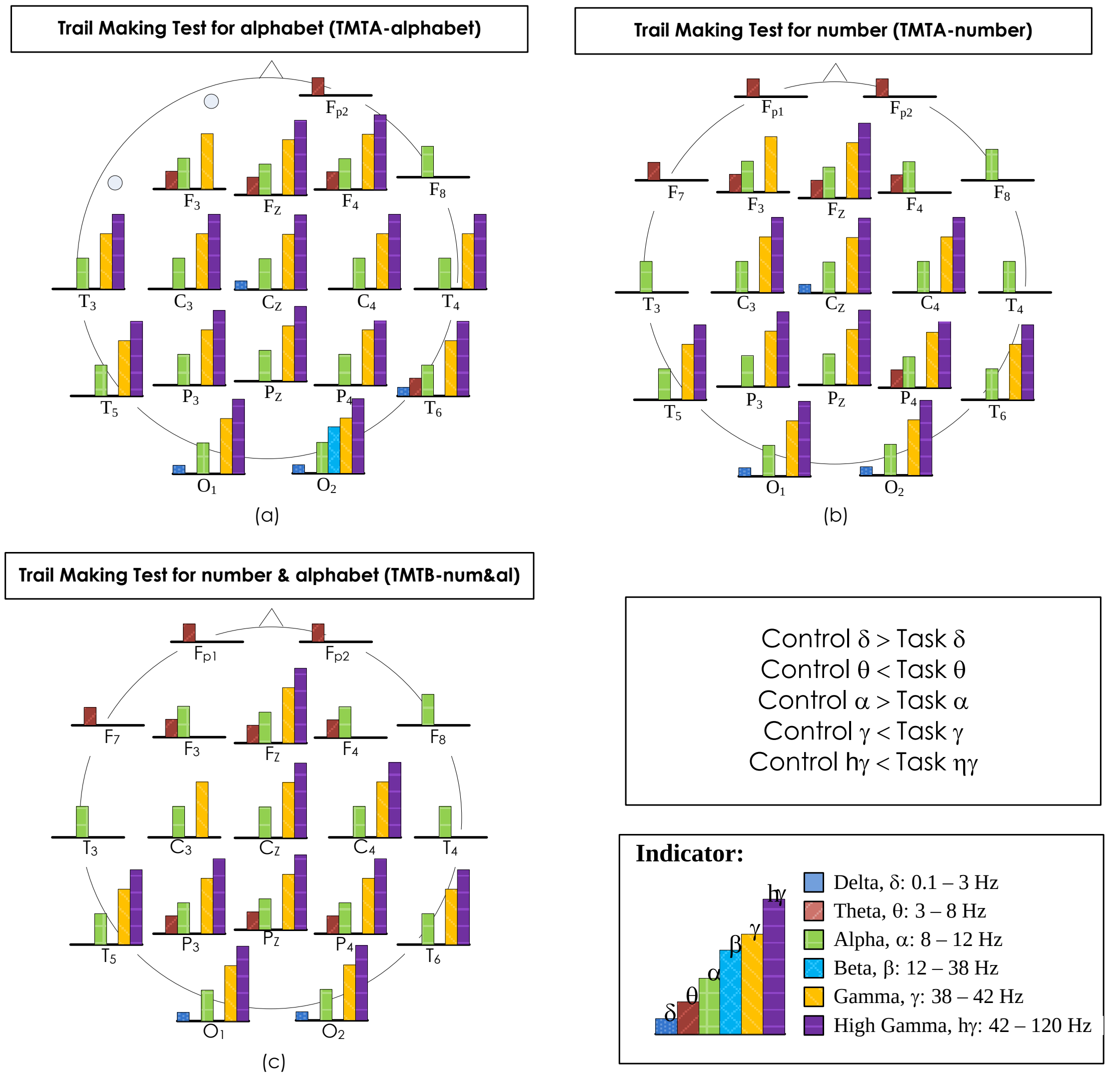


Figure 9 Significant frequency bands during Trail Making Test when compared to Control; (a) Trailing for alphabet (TMTA-alphabet); (b) Trailing for number (TMTA-number); (c) Trailing for number and alphabet (TMTB-num & al) sub-task

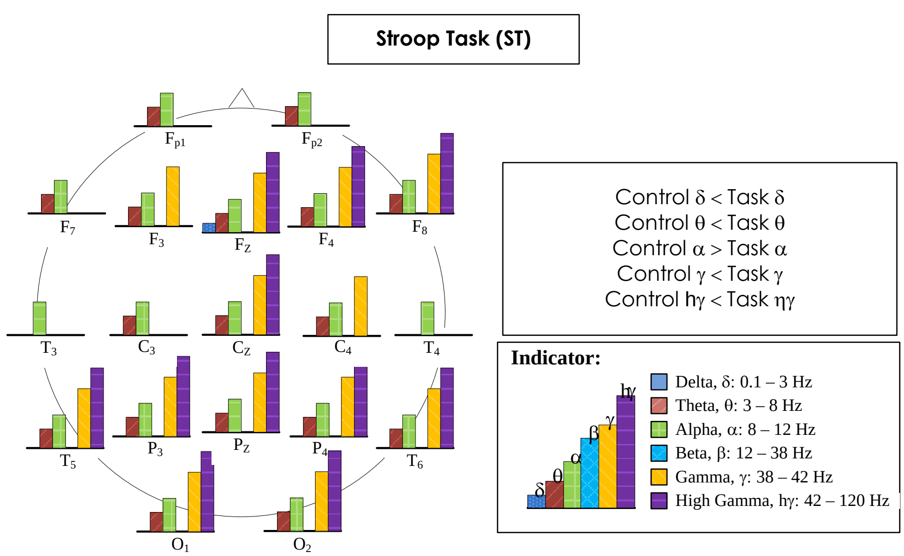


Figure 10 Significant frequency bands during Stroop Test when compared to Control

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