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MASTER THESIS

ELECTROPHYSIOLOGICAL CORRELATES OF CRITICAL-ANALYTICAL THINKING AND EXECUTIVE FUNCTIONING

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1. ABSTRACT

ELECTROPHYSIOLOGICAL CORRELATES OF CRITICAL ANALYTICAL THINKING AND EXECUTIVE FUNCTIONING

Critical thinking can be defined as purposeful and reasoned thinking that includes problem solving, decision making, estimating probabilities and formulating conclusions while using advanced skills for a particular situation and task. Critical thinking consists of two complementary elements; skills and dispositions. It is improvable and teachable. According to dual process theory, there are two thinking pathways; system 1 which is basic, fast and intuitive, system 2 which is more complex, slow and analytical. Since critical thinking can be considered as complex thinking, it might be related to system 2 thinking. Electrophysiology of our brain changes according to our mental states. Frontal EEG gamma activation is associated with insight and this might be a feature of critical thinkers. On the other hand, executive functions like inhibitory control and cognitive flexibility could be necessary to think critically. The aim of the study was to investigate electrophysiological correlates of critical thinking and explain critical thinking dispositions while considering 2 pathways. The first hypothesis was that system 2 thinking predicts critical thinking dispositions through frontal gamma activation. The second hypothesis suggested that executive functions also predict critical thinking dispositions. To test the model, structural equation modeling was used as the statistic method. According to results, the tendency to think critically can be predicted by system 2 thinking through frontal gamma band activity. However executive functions and critical thinking disposition was not significantly related.

Key words: analytical thinking, critical thinking, dual process theory, electrophysiology, executive functions

2. ÖZET

ANALİTİK DÜŞÜNME, YÜRÜTÜCÜ İŞLEVLER VE ELEKTROFİZYOLOJİK KORELATLARI

Eleştirel düşünme; belirli bir durum veya görev için gelişmiş yetenekleri kullanırken; problem çözümü, karar verme, olabiliteleri hesaplama ve sonuçları formalize etmeyi kapsayan amaca yönelik, akıl yürütülmüş düşünme olarak tanımlanabilir. Eleştirel düşünme iki birbirini tamamlayıcı bölümden oluşur; yetenek ve yatkınlık. Geliştirilebilir ve öğretilebilir. İkili işleyiş teorisine göre, iki düşünme yolu vardır: basit, hızlı ve sezgisel olan sistem 1 ve daha karnaşık, yavaş ve analitik olan sistem 2. Eleştirel düşünme karmaşık düşünme olarak ele alınabileceğinden, sistem 2 düşünme ile ilişkili olabilir. Beynimizin elektrofizyolojik aktivitiesi zihinsel durumumuza göre değişiklik gösterir. Frontal EEG gamma aktivitesi içgörü ile ilişkilidir ve bu eleştirel düşünenlerin bir özelliği olabilir. Diğer bir yandan engelleyici kontrol ve bilişsel esneklik gibi yürütücü işlevler eleştirel düşünme için gerekli olabilirler. Bu çalışmanın amacı, eleştirel düşünmenin elektrofizyolojik korelatlarını incelemek ve eleştirel düşünme eğilimini 2 yolla açıklamak idi. Birinci hipotez, sistem 2 düşünmenin eleştirel düşünme eğilimini frontal gamma aktivasyonu yolu ile öngörebilmesidir. İkinci hipotez ise yürütücü işlevlerin de eleştirel düşünme eğilimini öngörebilmesidir. Modeli test etmek için yapısal eşitlik modeli istatistik yöntemi olarak kullanıldı. Sonuçlara göre eleştirel düşünmeye yatkınlık frontal gamma aktivasyonu yoluyla sistem 2 düşünme tarafından öngörülebilir. Ancak yürütücü işlevler ve eleştirel düşünme eğilimi anlamlı derecede ilişkili değildi.

Anahtar kelimeler: analitik düşünme, bilişsel işlevler, elektrofizyoloji, eleştirel düşünme, ikili işleyiş teorisi,

3. INTRODUCTION AND PURPOSE

Recently, researchers from different perspectives have focused on the dual process theory. According to theory, there are two different systems determine reasoning. The first one is evolutionary old, automatic, fast, innate and intuitional to solve particular adaptive problems. The second system is specific to human, controlled, slow, analytic, learned and flexible (1).

Critical thinking involves thinking on one's judgments and decisions. When we critique our own thoughts or someone else's and consider it as logical, we engage in critical thinking (2). It is "purposeful, reasoned, and goal directed" (3). Thus it could be associated with the system 2 thinking.

Critical thinking is investigated by many intellects from different perspectives. In philosophy the focus is on argumentation. Critical thinking process is explained by identification, reconstruction and evaluation. When we face an argument, the first step is to identify the issue and decide if it is a real argument. The next step is to reconstruct the argument to understand the form of the argument's reasoning, and finally to evaluate the argument (4).

The educational perspective focuses on teaching and measuring critical thinking (5), Facione gathered many expert and created a consensus definition of critical thinking. The Dephi report suggested two necessary parts of critical thinking: skills and dispositions (6).

Critical thinking is studied in psychology as well. It is interested in how people think rather than ideal way of thinking and use some measurements to estimate analyzing and reasoning (5).

The control mechanism which manages different cognitive subprocesses and cognition, is defined as executive functions (7). The core executive functions are working memory, inhibition and setshifting ability (cognitive flexibility). Executive functions also related to fluid intelligence and reasoning (8).

Critical thinking is related to the prefrontal cortex activation (9). Cognitive representations of brainwaves have been studied in various researches. For example, while solving a problem, a quick comprehension that reinterprets the circumstance is named as insight and it is highly correlated with EEG Gamma activity (10).

Despite it is importance and it's relation to complex thinking systems, there is little research on critical thinking in cognitive neuroscience. Cognitive neuroscience is a dynamic field and in the center of new developments. While existing studies provides various information on critical thinking, the majority of this researches focus on educational techniques or philosophical argumentation. Understanding the cognitive and neuro-scientific process of critical thinking is important for all fields that are interested in critical thinking.

This research investigates cognitive and electrophysiological correlates of critical-analytical thinking. The goal of the study is to suggest a model explaining critical thinking dispositions. There are two pathways in the model; system 2 thinking to critical thinking dispositions while considering electrophysiological correlates and executive functions (inhibition, set shifting) to critical thinking dispositions.

The first hypothesis of the study is that system 2 thinking measured by cognitive reflexion test predicts critical thinking disposition through insight latent variable (frontal and fronto-central gamma activity) predicts disposition latent variable estimated by California Critical Thinking Inventory.

The second hypothesis of the study is executive functions underlie a base for critical thinking dispositions. Thus I suggested the following: set shifting and inhibition latent variables measured by Wisconsin card sorting test and stroop test respectively predict disposition latent variable

4.GENERAL INFORMATION

4.1 Thinking

The concept of "thinking" has been a controversial topic through history. Philosophers and scientists have been amazed by the organization that allows individuals to use their mind while considering something. The flexibility of one's thinking capability is remarkable. The control is not under immediate sensory stimuli or the necessity of immediate action (11). In the dictionary, thinking is defined as the action of using one's mind to produce thoughts (12) Thinking skills play a crucial role in everyday life reasoning, scientific methodology and philosophical argumentation.

Thinking is generally indicated by a focus of attention. Attention implies to maintain goal-directedness of thought. However the attentional competence is limited and sometimes declines. Along with current perceptual input, memory, which is not limited in capacity and ability to bring compatible information to ongoing thinking process, also provides input for our thoughts (11).

The dual process theory has been investigated by many cognitive psychologists. Kahneman received a Nobel Price for his study on decision-making. He focused on how we think and argued two main thinking systems. "System 1- fast, intuitive, and emotional; System 2- slower, more deliberate and more logical" (13). While system 1 can be counted as intuitive, system 2 thinking could correspond analytic thinking (14).

The difference between fast and slow thinking could correspond Freud's concepts of subconscious and conscious. For example all of us have wonderful talents like recognizing faces. We do it without obvious effort and very quickly despite the process must contain all the estimation. System two thinking contains a lot of effort so that clear physiological symptoms can be seen like dilations of pupils, alterations in heart rates and tension. These physiological changes enable certain objective quantitative estimations. It is conscious and needs consideration and attention. Standardized computation could be a

representative example that includes holding materials in our working memory. Fast thinking is sometimes incorrect and we need larger effort so that slow thinking replaces it. Slow thinking looks for additional information and estimates different components accord with their objective importance (15)

4.2. Critical Thinking

4.2.1. Definition of critical-analytical thinking

"Reasonable reflective thinking focused on deciding what to believe or do" is named as "critical thinking" by Ennis (16). He focuses on reasonableness, reflection, and the process of decision-making.

Analytical thinking is needed to determine or produce a problem to solve in an ambiguous situation. Reasoning is the main part for problem solving and analytical thinking; consists of controlling verbal stimuli to limit response alternatives while considering problem's result. Analytical thinking is used generally in circumstances with less-known parameters and results (17).

Critical thinking can be defined in various ways. One way to describe the concept of critical thinking is using cognitive skills in order to enhance the likelihood of preferred outcome. It is "purposeful, reasoned, and goal directed" thinking thus includes problem solving, decision making, calculating probabilities and formulating implications while utilizing sophisticated and efficient abilities for the specific condition and kind of thinking assignment (3).

Previous emphasizes of critical thinking was on cognitive part so it was considered as a "skill" or "correct assessing of statements" (18). The consideration was on procedures and system that regulates formal logic (19).

The changes of definition has led to consider more integrative view, in addition to have high cognitive skills, a critical thinker needs to possess powerful intention to realize

significance of good thinking and makes an effort to find better judgment (19). Khun presents critical thinking as a metacognitive competency instead of cognitive skill. She thinks that first order cognitive skills help to understand the world, however metacognitive skills (meta-knowing skills) enable us to know ours and others "knowing" (20)

4.2.2. Critical Thinking in Philosophy

In the literature there are three approaches about critical thinking. In philosophical approach, the emphasis is on the hypothetical critical thinker and it focuses on qualities and features of a critical thinker rather than behaviors the critical thinker can perform. Since it focuses on ideal critical thinker, it may present less opinion on how people think in reality (5). Critical thinking skills are very significant in order to construct philosophical arguments. Cognitive science could be originated historically from the Greek philosophers' emphasis on deductive reasoning which could be determined as inferring new logical information from an assumed true information. (11) Not only western philosophers but also post-classical Islamic intellectuals developed dialectic and argumentation theory. It is different from Hegelian "thesis-antithesis" concept in a way that it emphasizes argumentation as the role of path-finder. It was not only related to estimating the best way to solve problems but also about asking right questions (21). Thus argumentation theory thought in madrasah (Islamic school) might be seen as set of tasks focused on presenting thesis-antithesis against justifications directed to an argument.

4.2.3. Critical Thinking in Education

Even though the concept of critical thinking roots in philosophy and philosophers as old as Socrates, 20th century educational intellectuals like Ennis, Scriven and Fisher also focuses on it (22) The studies help educational practitioners on teaching and measuring higher order thinking (5). Because of multiple definitions of critical thinking, Peter Facione gathered and leaded an expert philosophers group to produce a consensus definition for the purposes of education and evaluation in higher education. They used Delphi method which consists of several steps; first collecting individual definitions of

panel members on the topic and then analyzing and revising the definitions until the consensus is reached (22). In the final report they stated that “We understand critical thinking to be purposeful, self regulatory judgment which results in interpretation, analysis, evaluation, and inference as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based” (6).

Delphi report recommended two main aptitudes for critical thinking: critical thinking skills and critical thinking dispositions. There is little sense if one has critical thinking competency (skills) but not want to focus on the critical discourse (dispositions) (22).

4.2.4. Critical Thinking Dispositions

Critical thinking consists of both cognitive skills and dispositions. In practice motivation leads learning and the will to use critical thinking skills as problem solving and decision-making creates a base for training and learning the critical thinking skills. Thus critical thinking skills and the dispositions to use critical thinking should correspond in practical and in significant way (23). Lai explains dispositions as “attitudes or habits of mind, include open and fair-mindedness, inquisitiveness, flexibility, a propensity to seek reason, a desire to be well-informed, and a respect for and willingness to entertain diverse viewpoints” (5).

According to Delphi Report inquisitiveness can be explained as intellectual interest and propensity for learning even if the knowledge is not necessarily applicable at that particular time. Open-mindedness is tolerance toward different opinions and being aware of self-biases. Systematicity related to organization, order, concentration and being persevering in inquiry. Analyticity associated with reasoning and problem solving, sensing probable theoretical or practical complexities and being alert all the time to the requirement of interference. Truth-seeking is to look for the best knowledge in the present situation, dare to ask questions and be objective even the results of the inquiry is not

supportive to one's own opinions and benefits. Critical thinking self-confidence is how much one relies his or her judgments and self trust to lead others to resolve complexities rationally. Finally maturity disposition characterized as being aware of some situations may have more than one option, there are some 'ill-structured' problems and judgments need to be determined by standards, context and proofs which may prevent accuracy (24).

Tishman and Andrade connect thinking dispositions to intellectual behavior (25). Dispositions are not defined as the abilities that people have but how people use those skills (26). The three conceptions of dispositions stated as ability, inclination and sensitivity (27). Inclination can be explained as tendency toward behavior when needed. Sensitivity is awareness of situations where certain behavior is necessary. Finally ability refers to the capacity of acting through behavior that is needed. The most important side of dispositions is when the effects of cognitive ability isolated, thinking dispositions can represent the residual variance in tasks related to judgments and reasoning (28).

4.2.5. Critical Thinking in Psychology

Psychologists and cognitive scientists like Halpern and Kuhn are interested in critical thinking (22). The focus is on how people actually think, rather than the ideal way of thinking. The emphasis is on observable components of thought like analyzing, interpreting and generating good questions. (5). The idea comes from philosophy. Aristotle's theory of syllogistic reasoning suggests that deductively valid arguments generally show one of the typical forms. Thus, learning deductive reasoning can be seen as learning an information process since one can notice and construct valid forms of argument (11)

Psychologists from different alignments argued two main models for processing information although they named differently. Some of the examples as follows; the first thinking system named as intuitive by Jung, experiential by Epstein, natural by Kahneman and first signal system by Pavlov. On the other hand the second one called as conceptual-

logical by Jung, analytical-rational by Epstein, extensional by Kahneman and second-signal system by Pavlov (29).

In social psychology, estimating the degree of this two thinking process could be useful to understand people whose receptivity rely on different kinds of communication. For individuals who think primarily in the first mode, the use of concrete examples, emotions and personal practice could be more influential. On the other hand, facts and logical arguments effects people who process information in analytical mode (29).

4.2.6. Neurological bases of critical thinking

It could be suggested that critical thinking is associated with neural substrates of the prefrontal cortex (9). Assuming that reasoning and problem solving related to integrating complex associations among stimuli, Kroger and his collugees used functional resonance imaging while using nonverbal reasoning problems. When complexity increased, the activation in parietal and dorsolateral prefrontal cortex among with anterior left prefrontal cortex also increased (30). On the other hand, structures in medial and ventral prefrontal cortex have role in emotional processes associated with moral reasoning and decision making (31).

4.3. Executive Functions

Executive functions could be defined as a control mechanisms that adjusts the operation of diverse cognitive subprocesses thus control the dynamics of cognition (7). Mentally presenting ideas, waiting to think before doing something, experiencing new and unexpected challenges, withstanding temptations and staying focused are all possible with executive functions (8).

Baddeley proposed a cognitive framework which is related to executive functioning. The multicomponent model of working memory consists of three parts; two of them related to speech-based, phonological information which could be named as

phonological loop and the other one is about visuo-spatial information (the visuospatial sketchpad). Along with them, there is also a central control system –the central executive- which could be in charge of the control and adjustment of cognitive processes (executive functions) (32). This capacities are often associated to frontal lobe functions (7). However, they do not match with a single structure, different cortical and subcortical neurol sustems come to play (33).

In the literature in relation to executive functioning three skills was mostly emphasized: inhibition and control of predominant reactions, updating of working memory images and shifting of mental sets, (7).

4.3.1. Inhibitory Control

Executive Functions includes inhibitory control which could be defined as the capability of controlling attention, acts, thoughts and emotions in order to compete internal or external attractions and behave more appropriately. Adaption to environment and choice selection can be possible with the help of inhibitory control (8).

Interference control at the level of perception (inhibitory control of attention) helps us for selective attention, concentration while chosing something and attention suppression to other stimuli. Another type of interference control could be cognitive inhibition. This phenomenon could be explained as restraining prepotent mental representations, withstanding extraneous or undesired thoughts, memories, information (8, 34).

Interference suppression and response inhibition are two main elements of cognitive control. Study of Bunge et al revealed that in both children and adults, there is a correlation between the ability to suppress interference and prefrontal cortex (mainly anterior insula). Inhibitory control of action also share similare neural bases (35).

One of the aspects of inhibitory control is self-control which includes controlling actions and emotions, resisting temptations and not behaving thoughlessly. Self control is necessary for considering all alternatives before jumping to a conclusion or not saying the answer that first pops in your mind and taking time to think for a better response (8).

4.3.2. Working Memory

Baddeley and Hitch argued that working memory corresponds a control system which can approach phonemically coded information. It has limited capacity in terms of storage and porcessing. It keeps information in mind and mentally play with it (34). There are two types of working memory; verbal and nonverbal (visuospatial) (8).

Working memory is necessary to consider alternatives, associate information mentally, realize relation between seemingly unconnected things, pick out components from a united whole. Thus without WM, reasoning is impossible (8). Working memory also important for long term memory and language comprehension. (37).

Working memory supports inhibitory control. The process could be explained as follows; by focusing the information that you are keeping in your mind, the possibility of that information will lead your acts rises, and the likelihood of an inhibitory error reduces (8).

4.3.3. Cognitive Flexibility

Cognitive flexibility could be defined as one's capacity to shift between cognitive sets in order to adjust dynamic environmental stimuli (38). It is crucial for people to cope and replace maladaptive thoughts with more steady and adaptive thinking. (38). Children at young age could keep information in their minds and inhibit prepotent reactions however cognitive flexibility (switching between rules) needed extended developmental process. Thus it can be said that cognitive flexibility appears later as children grow and builds on working memory and inhibition. (39).

Cognitive flexibility involves different types of perspective changes; spatially (seeing from a different direction), interpersonally (looking from another's point of view) and modifying how we think about something. In order to shift angles, it is necessary to inhibit our earlier perspective and initiate working memory another perspective (8).

4.3.4. Executive Functions and Reasoning

The capacity to reason, problem solving and realizing associations among items termed as fluid intelligence (40). Independent measures of executive functions and fluid intelligence have great correlation (41).

Executive functions (problem solving, decision making and WM) is linked to dorsalateral circuit of Prefrontal cortex. (37).

4.4. Electroencephalogram (EEG)

Proper estimation techniques could be helpful to observe brain states during occurrence of different types of mental activity (42). The patterns of electro-chemical movements across synapses, dentrites, soma, and cerebral spinal fluid in the extracellular field can be measured by EEG from the scalp (43). Using EEG for investigating mental states originated from Berger's paper about mental state changes and electrophysiological activity in 1924 (44). EEG also helpful to measure and differenciate pathological changes in brain activity, to divide some patients into categories according their neuropathy and mental illness, to figure out the nature of head trauma and observe the effects of pharmacological agents (42).

In ionic actions, a synchronized and repeating change creates an oscillation which could be detected in EEG (43). In recent years, brain oscillations have obtained excessive significance as constituent of sensory-cognitive processes (45). Oscillation bands range from <0.1 Hz to 600 Hz. Distinct ranges of oscillations (e.g., delta and theta) have been

characterized depending on specific cellular mechanisms while they associate to detectible behavioral relationships (43). However sometimes, our brain responses are variable. For example when event related potentials at p300 investigated with oscillatory methods, various studies found different responses to target signals on every oscillatory components from delta to gamma (46).

The frequencies could be line up as:

Delta: Ranges from 0.5 Hz to 3.5 Hz. Their amplitudes could be measured in 20-200 μv by electrodes.

Theta: Ranges from 4 Hz to 7 Hz. Their amplitudes could be measured in 5-100 μv by electrodes.

Alpha: Ranges from 8 Hz to 13 Hz. Their amplitudes could be measured in 5-100 μv by electrodes.

Beta: Ranges from 15 Hz to 30 Hz. Their amplitudes could be measured in 2-20 μv by electrodes.

Gamma: Ranges from 28 Hz to 48 Hz. Their amplitudes could be measured in 2-10 μv by electrodes.

When these frequecies overlap, EEG oscillations occurs. They could be detected by various filtering techniques (44).

4.4.1. Alpha wave and creative thinking

Alpha wave (generally in the range of 8-12 Hz) is primarily created in the parietal and occipital lobes. If alpha decreases or increases abnormally, anxiety symptoms may occur (47).

During the resting state, EEG frequencies of the alpha band are shown dominant in the EEG. However while doing cognitive tasks alpha band power decreases and the other frequencies increases. While the former one named as synchronization, the cognitive demand situation called desynchronization. EEG desynchronization demonstrates cortical activation (48).

Benedek et al showed frontal alpha synchronization while doing convergent and divergent thinking under top-down control (high internal processing demands) without bottom up processing (low internal processing demands). Thus, frontal alpha synchronization could be correlated with top down control rather than particular cognitive processes associated with creative thinking (47).

4.4.2. Beta wave and anxiety

Frontal beta waves between 15-18 Hz are associated to thinking and concentrating. If beta amplitude decreases, lack of concentration, attention problems, and ruminative thought occurs. Meanwhile increase in beta 2 waves (20-33 Hz) causes restlessness and anxiety. Afsaneh Moradi et al. suggested a treatment method. By enhancing frontal beta amplitude and decreasing beta 2, the symptoms of concentration problems, rumination, obsessive-compulsive disorder, anxiety have significantly decreases according to self-reports (47).

4.4.3. Gamma wave and insightful thinking

Spontaneous gamma band oscillations indicate the conscious level (42). High-frequency gamma band (40 Hz) usually related to insight problem solution. An immediate comprehension which resolves a problem while reinterpreting the situation is called insight or the ‘Aha! Moment’. (10). An unconscious processing underlies insight (49).

Kounios and Beeman used EEG and fMRI to study insight while comparing insight and analytic problem solving. If the solution came in awareness immediately it grouped as insight, and if gradually, it is called as analytical processing. The insight effect demonstrated in right anterior temporal lobe. On the other hand, before the problems presented which are solved with insight, there was a greater activation over temporal lobes and over mid-frontal cortex. The results from fMRI showed mid-frontal activity that starts in the anterior cingulate. This area often associated with cognitive processing (10).

Sheth et al revealed gamma band increase in fronto-central and frontal electrode regions during problem solving. When participants correctly solved the problems, greater right prefrontal cortex activation was observed (50).

Gamma activity changes can be seen in neuropsychiatric disorders. Patients with schizophrenia demonstrate decrease in gamma amplitudes during negative symptoms and significant increase can be detected in gamma while having positive symptoms like hallucinations. Alzheimer Disease may lead reduction whereas higher gamma activity can be seen epilepsy (42).

5. METHOD AND MATERIALS

5.1. Participants

30 healthy university students (15 females, 15 males) mean age 21,6 (max 25 min 18) recruited for this study. Any existing neurological or psychiatric disorder diagnosis or related medicine use at the time of measurement was eliminated. Participants were informed about the details of study at the beginning and all of them signed the written informed consent. The experiments were done in Medipol Mega hospital complex. The protocol of the study has been approved by the Ethics Committee of Istanbul Medipol University noninvasive clinical studies in 31.05.17

5.2. Experimental Design

The experiment has two stages; assessment of executive functions, critical thinking dispositions and eeg recording. EEG recording and neuropsychologic assessment held in two separate days in order to eliminate participant's fatigue affect for the study.

5.3. Behavioral and Neuropsychometric Evaluation

Self administrated questionnaries to assess critical analytical thinking tendencies:

- Cognitive flexibility inventory (CFI)
- California Critical Thinking Disposition Instrument (CCTDI)
- Cognitive Reflexion Test (CRT)

Behavioral tests to assess executive functioning:

- Wisconsin Card Sorting Test (WCST)
- Stroop Test

5.3.1. Cognitive Flexibility Inventory (CFI)

Cognitive flexibility inventory was created as a 20-item self-report measure, estimates three aspects of cognitive flexibility: a-) the inclination to perceive challenging circumstances as manageable; b-) the capacity to perceive different alternative statements for life events and human acts; c-) the competence to accomplish various alternative solutions to problematic status. Participants answer 5-point Likert scale about their feelings and beliefs related to behavior. It has 2 factors structure; alternatives subscale is composed of 13 items (to measure aspects b and c) and control subscale involves 7 items (to estimate aspect a) (38).

The Turkish adaptation, validity and reliability of the cognitive flexibility inventory was studied in 2012 by Gulum and Dag (51)

5.3.2. California Critical Thinking Disposition Inventory (CCTDI)

The California Critical Thinking Disposition Inventory (CCTDI) (52) is one of the first measures that conceptualize dispositions toward critical thinking from the APA Delphi Report (24). They stated seven dispositions: inquisitiveness, open-mindedness, systematicity, analyticity, truth-seeking, critical thinking self-confidence, and maturity.

Considering Delphi Report's agreed description of critical thinkings theoretical basis, California Critical Thinking Disposition Inventory (CCTDI) aims to estimate critical thinking disposition (53). After factor analysis, the measure included six disposition subscales: open-mindedness (12 items), analyticity (10 items), truth seeking (7 items), systematicity (6 items), inquisitiveness (9 items), and self-confidence (7 items). It is 51-item self-report measure, contains 6 points-Likert scale. (54)

The item numbers of (5, 6, 9, 11, 15, 18, 19, 20, 21, 22, 23, 25, 27, 28, 33, 36, 41, 43, 45, 47, 49, 50) negatively scored. Every subscale score are divided by the number of questions and multiplied by 10. Thus a subscale's score can range between 6 to 60. For

total CCTDI assessment, the score under 240 is considered as ‘low’, between 240-300 is considered ‘middle’, and over 300 is defined as ‘high critical thinking ability level’. (54)

CCTDI was adopted to Turkish population (55).

5.3.3. Cognitive Reflexion Test

The scale developed based on the system 1- system 2 thinking theories. It consists of 3 open-ended mathematical questions; measures cognitive ability, incorrect ‘intuitive’ answers and time preference. (56).

The answers were scored as true or false and participants preferred time to answer was recorded.

5.3.4. Wisconsin Card Sorting Test

To estimate complex cognitive strategies in normal individuals, Wisconsin Card Sorting Test was created. It was developed by Berg in 1948, and Heaton gave its final form in 1981 (57,58). It assesses mental set shifting, problem solving (7) and abstract abilities for both normal and brain-damaged individuals (59) and cognitive flexibility (38).

The test consists of 128 response cards (2 identical decks of 64 cards), 4 stimulus cards and a scoring form. There are 4 different figures (plus sign, circle, star and triangle), different number of items (1, 2, 3 or 4 items on each card) and 4 colors (red, freen, yellow, blue) mixed in all cards. There is a standard order written on the back of the cards. Participants are asked to find the matching rule; by color, or number, or figures. The tester reinforces the participants for every match by saying true or false. The participants are expected to find the rule depending on the reinforcements. When a set is completed (with successive 10 correct answers) a new rule starts and participants are expected to change their set. The tester records and measures total number of correct responses, total number of errors, perseverative responses, non-perseverative errors, perseverative errors and

categories.

The Turkish adaptation, validity and reliability of the Wisconsin Card Sorting Test was done by Karakas et al in 1996 (and updated form exists in BİLNOT Battary (60).

5.3.5. Stroop Test

The test was developed by Stroop in 1935 and has been used to measure resistance to interference, focused attention, inhibitory control and cognitive flexibility (61, 38, 62). The test consists of 30 colored words and 30 colored boxes and a black-white answer sheet. Participants were asked to read the color words that are printed in the ink of the same color. The tester recorded the time. After, participants were asked to read the color words (such as green) printed in the ink of different color (such as red) and the time also recorded. He participants had to ignore the meaning of the world thus inhibit their prepotent response) on the other hand focus and say the color of the ink. This process makes people slower (8). The difference in time for reading the words shows us the interference. As the difference in time become larger, the inhibitory control decreases. The error rate, spontaneous correction and the difference in time was also recorded.

In this study, The Stroop Test TBAG form was used. The Turkish standardization of the test is a study of Karakas et al (63,64) at part of BİLNOT battery (60).

5.4. EEG Recordings

All EEG recordings were taken in Medipol University Hospital, Remer, Clinical Electrophysiology, Neuroimaging and Neuromodulation Research and Application Center, EEG Laboratory. All subjects were recorded in a isolated room and dimly lit. After participants settled in room, they were informed about the details of EEG recording and consent form was filled. After the preparation completed, they brought into isolated room (faraday cage) for recordings.

After 4 minutes eyes open and 4 minutes eyes closed, total 8 minutes spontaneous EEG recordings, Oddball visual and auditory paradigm was applied. However in this study, only spontaneous EEG recordings was used. It was recorded from 32 Ag/AgCl electrodes with an elastic cap (easy cap), according to the international 10–20 System with Brain Amp 32-channel DC system machine. Band limits was 0.01–250 Hz and digitized on-line with a sampling rate of 500 Hz. In addition, A1 and A2 reference electrodes were placed in right and left earlobes. All impedances kept below 15 kΩ. In order to detect and filter the eye movements, EOG was recorded from medial upper- and lateral orbital rim of the right eye with Ag/AgCl electrodes.

5.5. EEG Analysis

EEG data pre-processing and EEG analysis were performed by Brain Vision Analyzer 2 Software. F_3, F_4, FC_3, FC_4, C_3, C_4, CP_3, CP_4, TP_7, TP_8, P_7, P_8, P_3, P_4, O_1, and O_2 were analyzed. Fast Fourier Transform (FFT) was used for analysis. The results was exposed to statistical analysis by the help of IBM SPSS Statistics 22 programme.

5.5.1. EEG data preprocessing

After EEG recording, the data was subjected to preprocessing to become ready for analysis. The raw EEG datas was divided into 2 parts (eye open and eye close) with the help of the eye closed sign. Then splited into 1 second durations and total 240 part. The EEG and EOG data set inspected with naked eye and artifacts were rejected off-line. Epochs with muscle artifacts, eye movements, eye blinks were rejected manually.

5.5.2. Power Spectrum Analysis

After eliminating artifacts and noise and dividing into one second epochs, Fast Fourier Transform (FFT) was applied. After that, FFT data averaged for eyes open and eyes closed states seperately. From the average data, alpha (8-13), beta (15-25) and gamma (25-48) activity were investigated. Peak points for every frequency value were

recorded in terms of $\mu V2$ for statistical analysis. These estimations were done in Brain-Vision Analyzer Programme 2.1.

5.6. The Method and Approach for the Statistical Analysis

All the data were extracted to Data Analysis and Statistical Software (Stata 14) to use structural equation modeling feature in order to construct the proposed model.

As it was mentioned below, this research aspires after providing a consistent empirical background for explanation of the process of the critical thinking. In this regard, the main hypothesis and the research path is that System 2 thinking is the mechanism which effects the critical thinking disposition through the frontal activity. In this regard, one of the most important question is the relation between the complex executive functions – e.g. setshifting (or the ability of realization of the alternatives) and inhibition- and frontal activity. Towards the goal of investigation of the critical thinking process, we focus on two of the most frequently used executive functions in the literature which are the setshifting and inhibition and the frontal and centra-frontal activities with cognitive flexibility which is estimated by electroencephalography (EEG) and Cognitive Flexibility Inventory. It can be remarked that the usage of EEG results with the Latent Variable Model in order to determine the effect of frontal lobe activities which effect the critical analytical thinking process is the contribution of this research to the literature for the examination of the relation between critical analytical thinking procedure and various (complex) executive functions. When it is mentioned about the setshifting, it is implied that the complex cognitive strategies for the normal individuals when they encounter with the complex task which includes the different alternatives. The “Inhibition” in this regard, implies the withstanding the prepotent responses for the normal persons who confront with unexpected and undesired situations.

One of the most significant feature of this research is to try the precise relation between frontal activities and executive function through the critical analytical thinking approach in terms of structural equation modelling (SEM) approach. Since the bare correlation and pairwise relations, or the other factor analytical approach, have various significant problematique and limitations (65). It can be indicated that one of the most significant weakness of the bare correlation analysis is the problem of whether lack of correlations can reveal the independence of common used executive functions and their effect on critical analytical thinking (66). Therefore, we focus on three factors which effect the "*critical analytical thinking*" process. Two of them are setshifting and inhibition which are mostly common used executive functions in the literature. And the other factor which is used in the research is coined as "frontal" activity which reflects the cognitive flexibility and gamma activities of the normal person. In this regard, we examine the relation between these executive functions and critical thinking disposition at the level of latent variable rather than manifest variable. Namely, from the jargon of the SEM literature, it is used the some "commonality" among the tasks which are measured by various tests mentioned at the introduction and method parts by extracting the parallel factors which explain the same underlying determinants. In other words, we try to determine the "unobserviable" factors which are executive functions and critical thinking disposition from the observed/manifest variables which were acquired from the psychological tests mentioned above.

There are some significant reasons are why this statistical model is chosen for this analysis:

1) One of the outstanding reasons is the exclusion (or minimization) of the "impurity" problem. It is not possible that eye-catching varieties in necessities of nonexecutive tasks like visuospatial processing and language) can veil the existence of hidden commonalities among the executive functions mentioned above. This problem lays emphasis on so-called task impurity issue (67).

2) The other important issue, while choosing latent variable model and the Structural Equation Modelling approach, is to yield coherent judgement about what the specific neuropsychometric tests and tasks evaluate and to explain the process of the critical analytical thinking through these executive function. It is believed that this approach and test technique commit to the mitigation of the validity problem for the construction critical thinking process and experimental design of future research.

5.7. The Statistical Analysis of the Model

There are some dedicated goals of this research when examining the process of the critical analytical thinking by following the specific experimental behavior literature. The first major goal of this research is to determine the precise coherent observed/manifest variables which reflect the executive functions and frontal lobe activities that are unobserved/latent variables. This determination process is named as "modelling" in terms of SEM jargon. In this regard, at the first part, the "Confirmatory Factor Analysis" (CFA) is chosen for the determination process (or modelling) when examining the most accurate tests and/or factors which can explain the executive functions and frontal lobe activities rather than pairwise correlation analysis and the Exploratory Factor Analysis (EFA) which only can show the individual differences in terms of commonalities. Beside this, the interpretation of the results of this analysis techniques are intricate and have deliberate issues. Namely, it is tried to choose the most useful and effective tests and sub-outcomes of these tests mentioned above which evaluate "unobservable" executive functions and frontal activities.

The second major aim of this research is to show whether the executive functions and frontal activities can be distinguishable or not in the disposition and process of critical thinking. It is focused "two-factor", "three factor" and "sub-section" modelling in order to determine to what extent these factors can explain and effect the critical thinking process as whole or a partial manner. Although the usage of CFA is outstanding in the set of modelling, it is utilized from the EFA as subordinate factor analysis method while

seeking the compatible determinants which explain same commonality of the various hidden factors.

5.7.1. Theoretical One-Factor Models

The meaning of the "one-factor" model is the usage of confirmatory factor analysis in order to compare the models for each independent executive function, critical thinking disposition and insight activity. In this regard, one factor modelling is a type of hypothesized model and theoretical construction for indicators (or factors) through the test scores and the other type of observed (manifest) variables in a manner of convenience with the scientific-empirical literature in order to determine the unobserved variables or factors which indicate the critical analytical thinking process for the sake of this research in this thesis.

In a line with the jargon of Structural Equation Modelling (SEM) and Confirmatory Factor Analysis (CFA), the latent variable, or unobserved factors are depicted graphically with oval circles and the manifest, or observed, variables are indicated, fittingly the traditional use, a rectangle in the graphical and visual representation of the SEM and CFA. In this regard, "Inhibition", "Setshifting", "Insight" and "Disposition" are the latent factors which are unobserved and used for the determination of the critical analytical thinking process.

5.7.1.1. Executive Functions

5.7.1.1.1. Inhibition:

There is a set of determinants which are used for determining the "Inhibition" factor. As mentioned in the theoretical setup, the stroop scores are used as indicators which reflect the inhibition level. Specifically, substroop scores which are coded in the data set as stroop_sure_fark, stroop_duzeltme and stroop_yanlis are the hypothetic setup for the confirmatory analysis and the one factor modelling. Beside this, as convenient with the metric and regression jargon, age and gender are used for the statistical consistency as "general controls" or "*covariates*". The graphical representation of the one-factor model for the inhibition as CFA is depicted in the figure 5.7.1.1.1.1. In a line with the jargon of SEM, age, gender, stroop fixing, stroop time difference and stroop mistake are manifest/observed variable when inhibition is the latent/hidden variable.

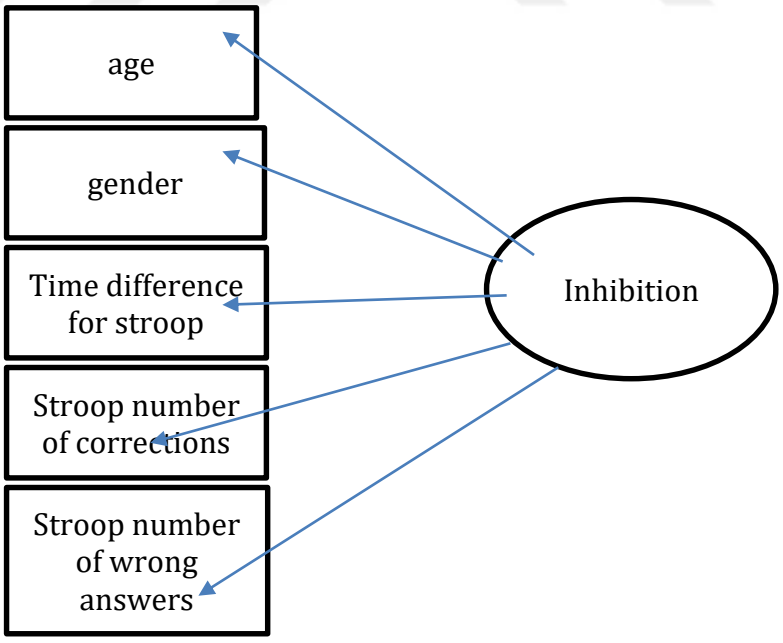

Figure 5.7.1.1.1.1.: The Hypothetical Model for Response Inhibition

5.7.1.1.2. Setshifthing:

In a similar manner with the modelling of the inhibition factor through one-factor modelling, subparts of the Wisconsin Card Sorting Test are used as observed variables which indicates the ability of realization of the alternatives termed as “setshifting” in the model. There are thirteen categories of the outcome of the Wisconsin Card Sorting Test in the data set which is used for this research. However, all of the sub-outcomes of the Wisconsin Card Sorting Test are not the suitable and convenient for the determination of the setshifting function. In this regard, in the light of the empirical literature, it is picked seven indicators from the Wisconsin Card Sorting Test which are total errors, total answer, perseverative responses, percentage of perseverative errors, non-perseverative errors, percentage of conceptual level responses, and failure to maintain set.

Beside this, since frontal beta wave has relation to anxious and obsessive thinking, it it could effect the set-shifting mechanisms of healthy population as well. Thus it added to model as well.

And then, the hypothetical model is total errors, total answer, perseverative responses, percentage of perseverative errors, non-perseverative errors, percentage of conceptual level responses, and failure to maintain set of the Wisconsin Card Sorting Test and frontal beta activities are the indicators for the setshifting function. The graphical representation of the one-factor model for the inhibition as CFA is depicted in the figure

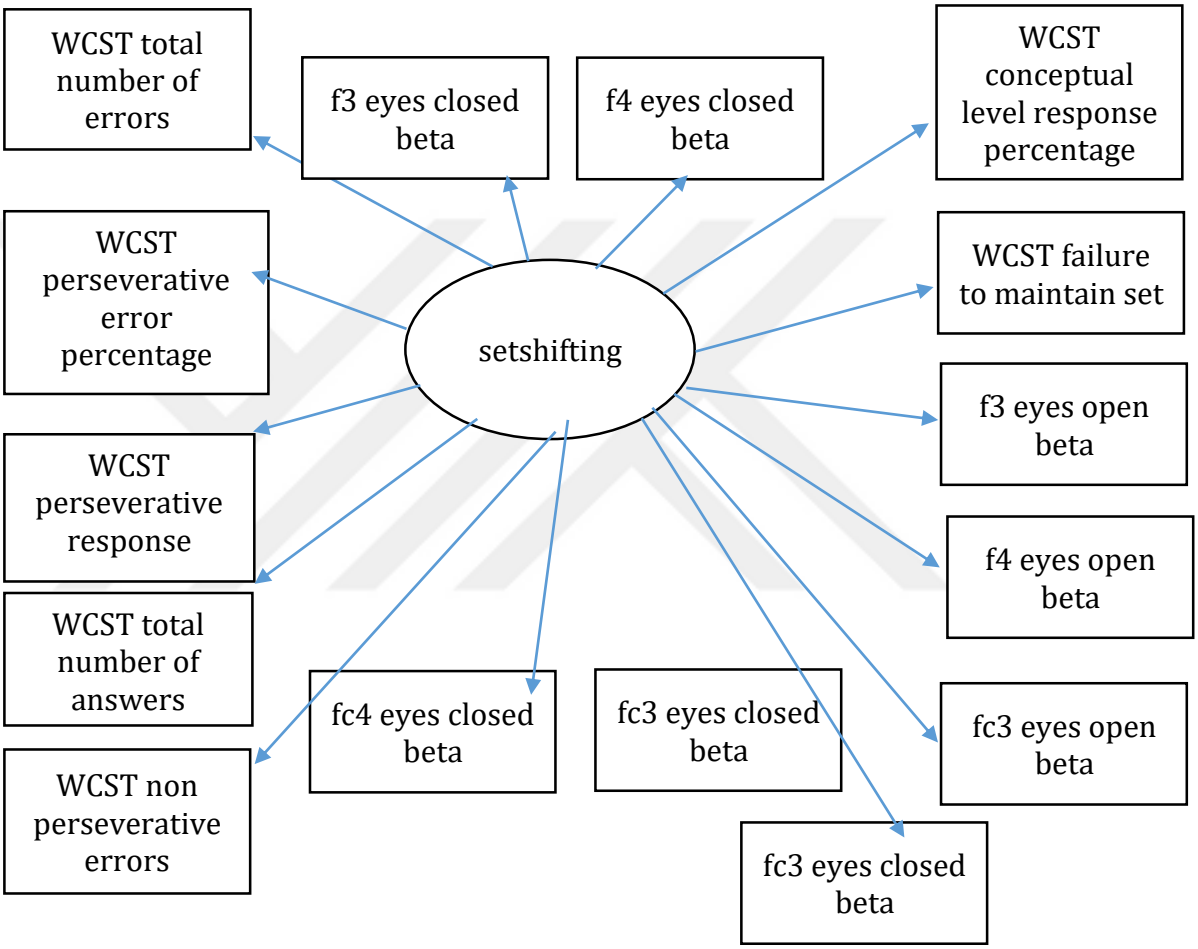

Figure 5.7.1.1.2.1: Theoretical Model For Setshifting

5.7.1.2 Insight

Insight could be defined as sudden comprehension of a situation while reinterpreting the problem. Insight is associated with EEG Gamma activity (10). Cognitive flexibility, on the other hand, is realizing alternatives the insight may not be possible without it.

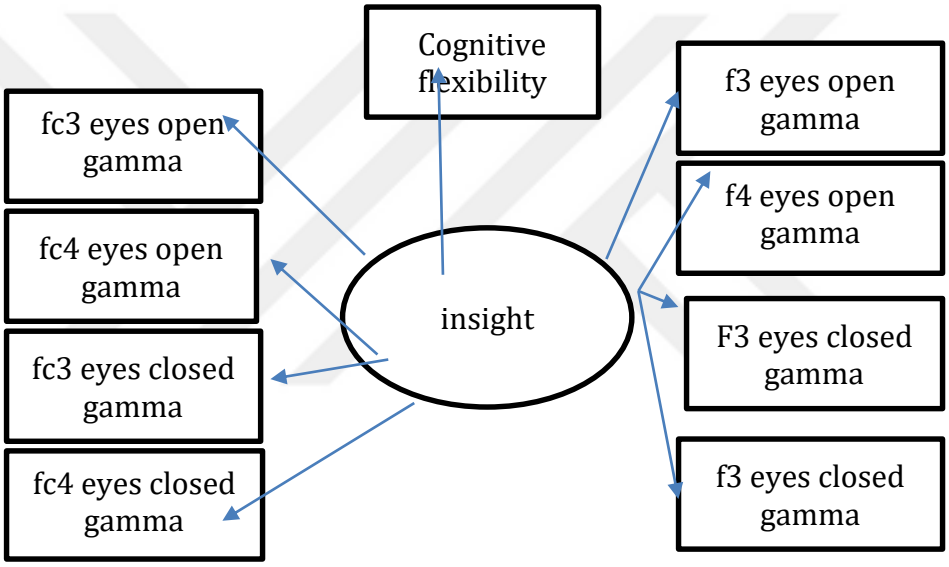

Figure 5.7.1.2.1.: Theoretical Model for Insightful Thinking

5.7.1.3. Critical Thinking Disposition:

Critical thinking dispositions originated from the Delphi method used by Facione, and essential part of critical thinking (6).

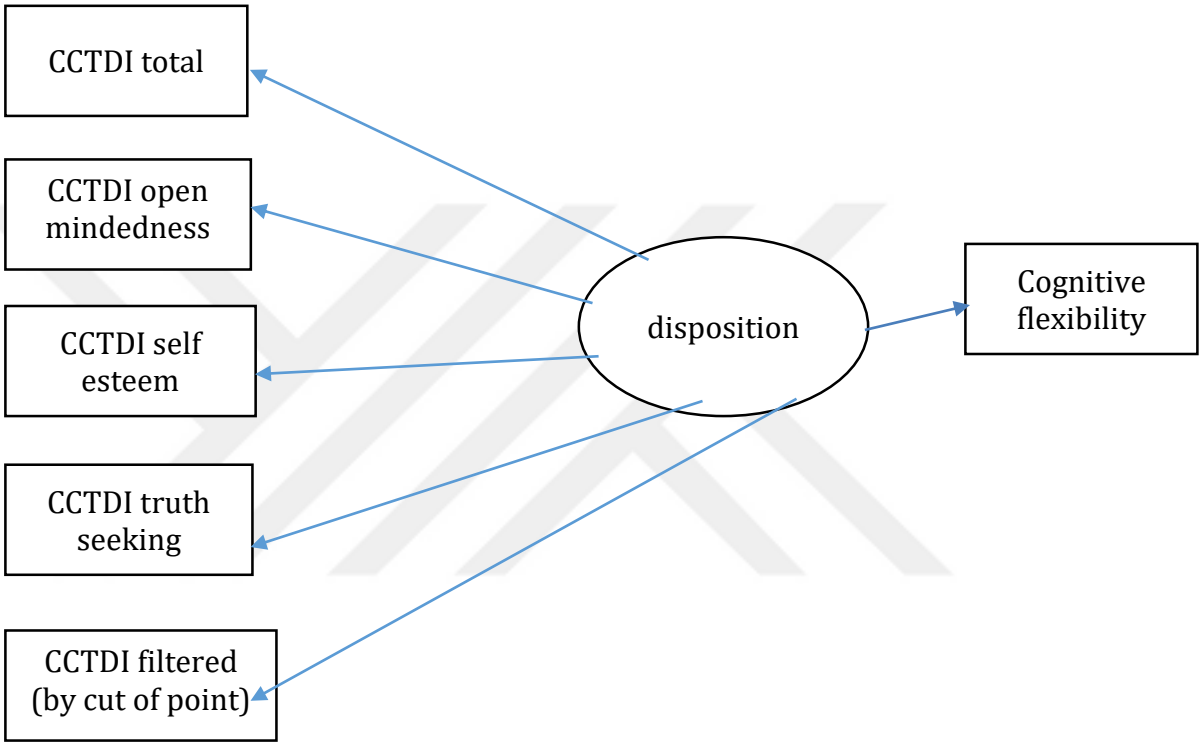

Figure 5.7.1.3.1.: Theoretical Model for Critical Thinking Dispositions

5.7.2. Theoretical Two-Factor Models

5.7.2.1. Setshifting-Inhibition:

As I mentioned above, inhibition and setshifting are 2 main executive functions. They have separate organizations and processes however they may affect eachother (8).

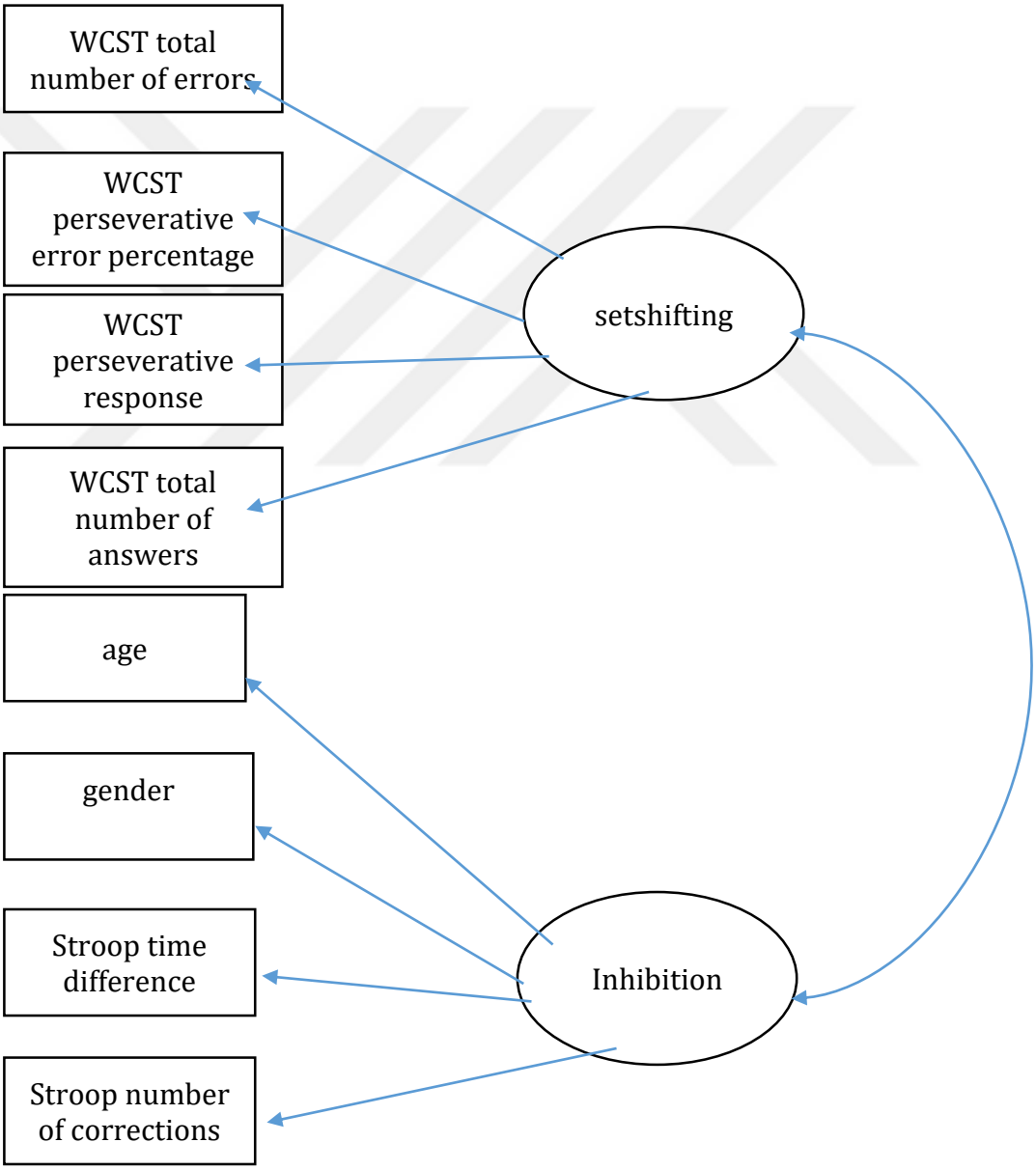

Figure 5.7.1.3.1.: Theoretical Model for the Relation Between Setshifting and Inhibition

5.7.2.2. Inhibition-Insight:

Reinterpretation is necessary for insight (10). Without inhibiting our thoughts, realizing alternatives and choice selection can not be possible (8). Thus the model expores whether inhibiton can predict insight.

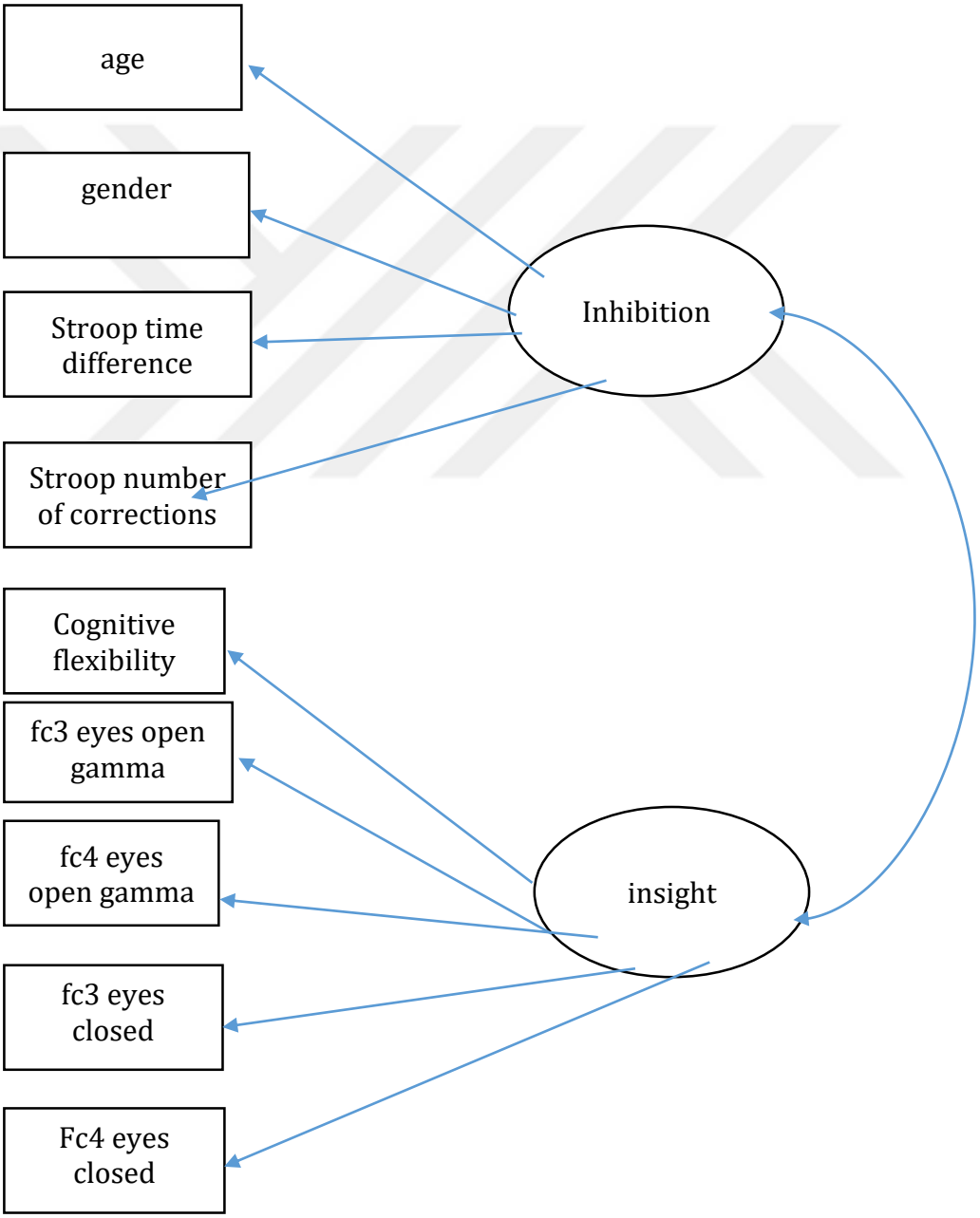

Figure 5.7.2.2.1.: Theoretical Model for the Relation Between Inhibition and Insight

5.7.2.3. Inhibition-Setshifting:

As a complex executive function, setshifting develops later than inhibition and may build up on it (10). Thus in this model, it can be suggested that setshifting can be predicted by inhibition.

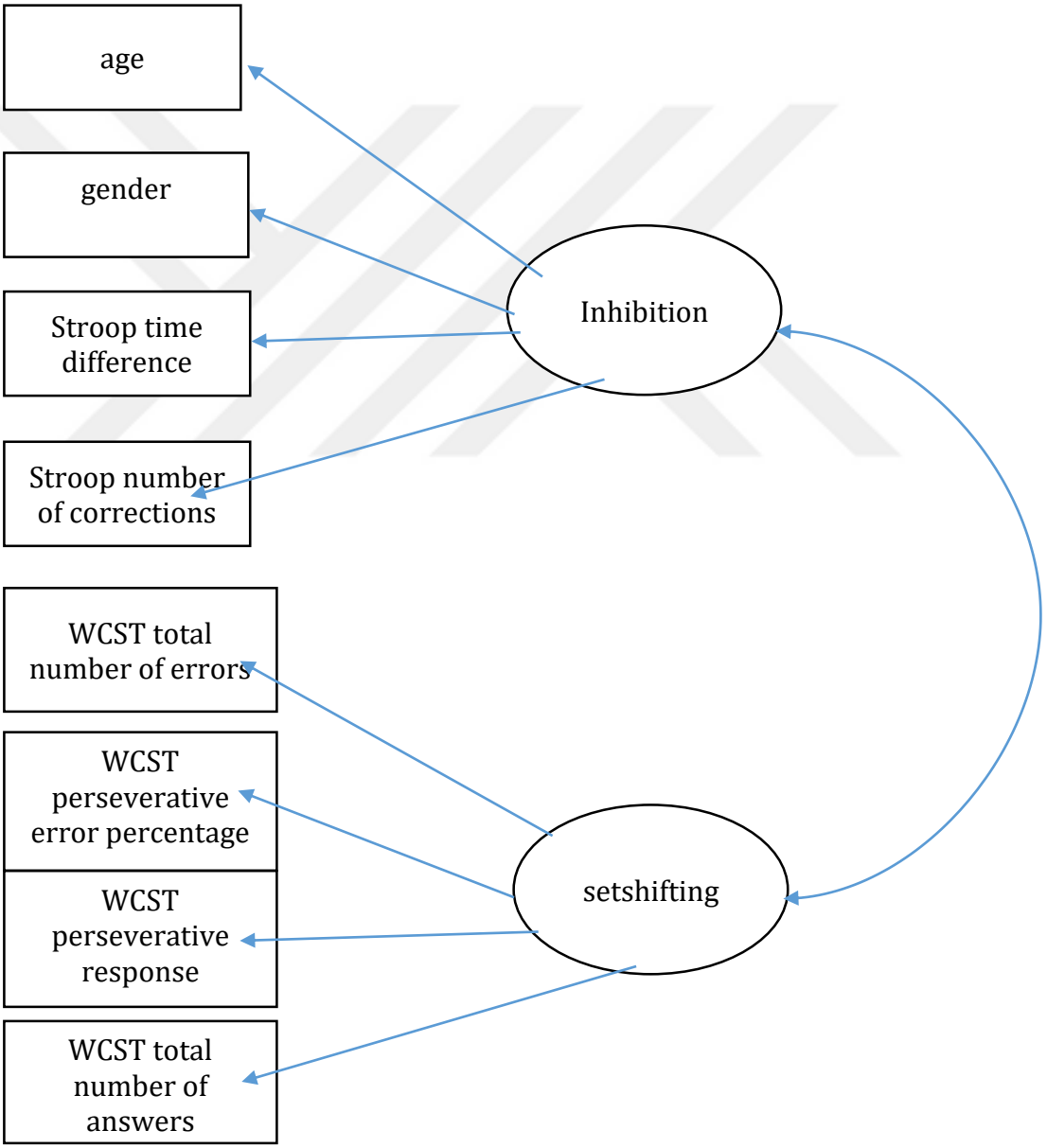

Figure 5.7.2.3.1.: Theoretical Model for the Relation Between Inhibition and setshifting

5.7.2.4. Setshifting-Frontal Activities

As a complex cognitive process, setshifting might lead frontal lobe activity (37). In the study, frontal gamma activity was associated with insight, thus the ability to shift among mental sets would predict insight.

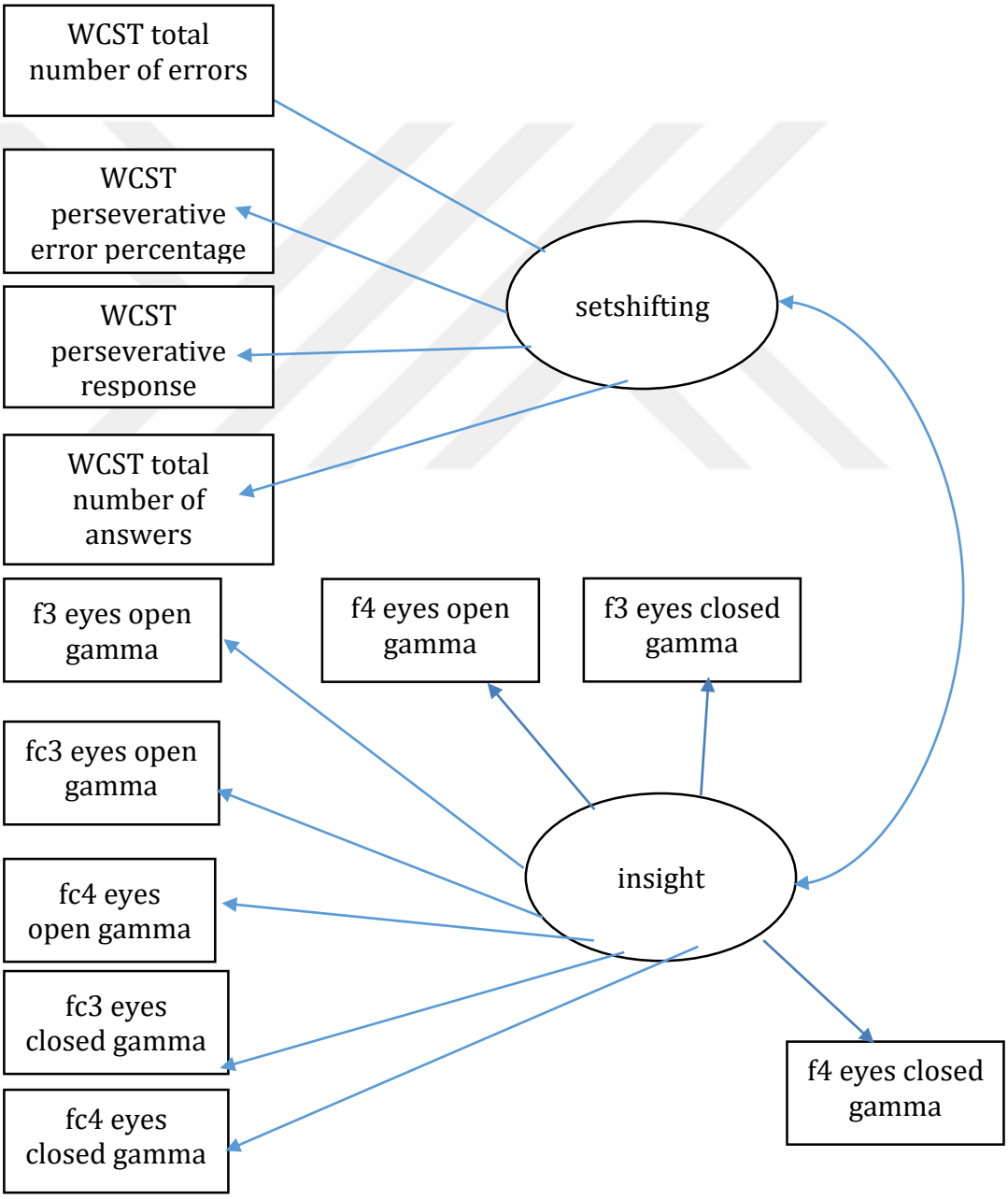

Figure 5.7.2.4.1.: Theoretical Model for the Relation Between Insight and setshifting

5.7.3. Theoretical Three-Factor Model

Executive functions are associated with prefrotal lobe activity (37). Ther might be a relation between executive functions and frontal gamma activity, thus insight latent variable.

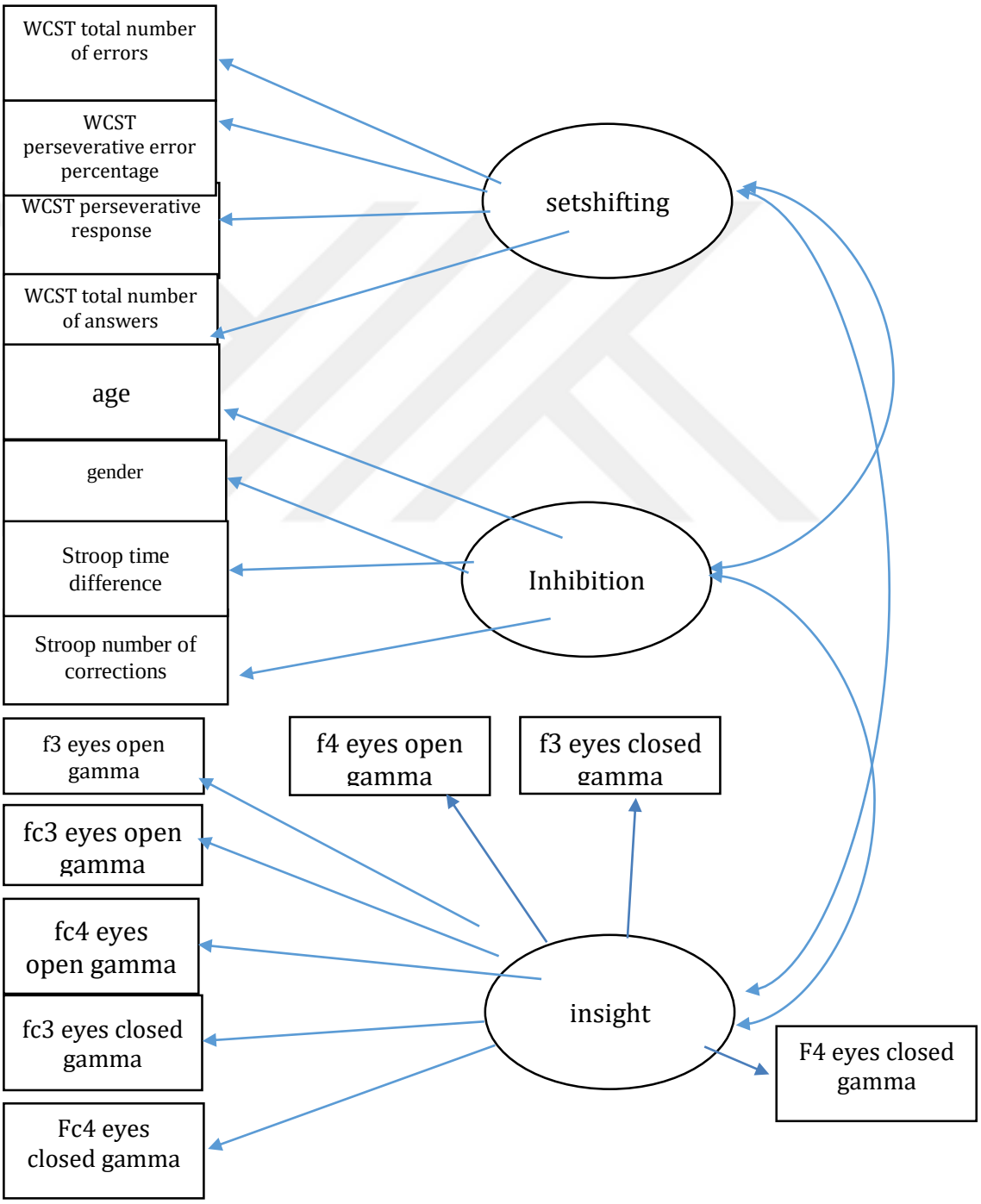

Figure 5.7.3.1.: Full Three-Factor Model Between Executive Functions and Insight Activity

6. RESULTS

6.1. Preliminary Data Analysis

After the introduction and the discussion part, it is revealed a summary of descriptive statistics for the collected test and estimation data. There are five main measures are used which are Stroop, Wisconsin Card Sorting Test (WCST), California Critical Thinking Disposition Inventory (CCTDI), electroencephalography (EEG), Cognitive Flexibility Index (CFI) and Cognitive Reflection Scale (CRS). It is examined three subparts of Stroop test; thirteen subparts of the Wisconsin Card Sorting Test; eight subparts of CCTDI; twenty four subparts of the EEG. Because of the theoretical background and major focus of this article, it is not used all of the subparts of the test which were examined at the process of the research. For the two target executive functions, insight activity, and Critical Thinking Disposition, the summary of descriptive statistics is shown in Table 6.1.1.

Table 6.1.1.

Descriptive Statistics for the Measures Utilized in the Confirmatory Factor Analysis and Structural Equation Model (N=28)

Test Scores	Mean	Standard Deviation	min	max	skewness	kurtosis
Cognitive flexibility	76.43	7.86	54.00	90.00	-0.56	3.66
CCTDI inquisitiveness	39.75	4.96	31.00	49.00	0.17	2.25
CCTDI analyticity	42.39	5.85	31.00	55.00	-0.14	2.67
CCTDI open mindedness	49.64	4.79	37.00	60.00	-0.05	3.68
CCTDI self esteem	32.64	4.26	24.00	42.00	0.09	2.83
CCTDI truth seeking	31.11	5.25	16.00	41.00	-0.50	3.84

CCTDI systematicity	27.32	3.03	21.00	34.00	-0.08	2.58
CCTDI total	224.18	18.38	185.00	259.00	0.04	2.24
CCTDI filtered according to cut of point	1.29	0.46	1.00	2.00	0.95	1.90
Cognitive reflexion test	1.32	1.12	0.00	3.00	0.14	1.66
Stroop time difference	32.46	12.80	14.00	79.00	1.86	7.49
Stroop number of errors	0.46	0.74	0.00	2.00	1.22	2.94
Stroop number of corrections	1.25	1.08	0.00	4.00	0.76	2.98
WCST total number of answers	90.46	21.33	67.00	128.00	0.73	2.06
WCST total number of errors	20.39	15.98	5.00	67.00	1.40	4.20
WCST total number of correct answers	69.75	7.73	60.00	86.00	0.56	2.02
WCST number of completed category	5.54	1.10	2.00	6.00	-2.19	6.33
WCST number of perseverative responses	12.21	10.42	3.00	41.00	1.58	4.39
WCST number of perseverative errors	11.36	9.45	3.00	38.00	1.57	4.37
WCST perseverative error percentage	9.43	8.05	0.00	29.00	1.18	3.25

WCST number of nonperseverative errors	11.27	6.45	4.41	29.68	1.49	4.31
WCST conceptual level responses	62.25	6.23	44.00	72.00	-0.56	4.06
WCST conceptual level response percentage	90.84	96.58	34.37	578.00	4.82	24.88
WCST Failure to maintain set	0.43	0.63	0.00	2.00	1.16	3.24
WCST learning to learn	-1.70	5.80	-16.00	16.67	0.58	5.92
f3 eyes open alpha	0.46	0.45	0.05	1.85	2.05	6.41
f4 eyes open alpha	0.44	0.46	0.04	1.90	2.24	7.52
fc3 eyes open alpha	0.42	0.39	0.06	1.60	1.81	5.45
fc4 eyes open alpha	0.40	0.42	0.06	1.82	1.91	6.29
c3 eyes open alpha	0.60	0.65	0.05	3.13	2.44	9.55
f3 eyes closed alpha	0.90	0.70	0.09	3.16	1.38	5.03
f4 eyes closed alpha	0.90	0.80	0.08	4.24	2.69	12.09
fc3 eyes closed alpha	0.89	0.74	0.10	3.14	1.51	4.78
fc4 eyes closed alpha	0.86	0.81	0.04	4.45	3.21	15.08
f3 eyes open beta	0.21	0.28	0.02	1.26	2.56	8.90
f4 eyes open beta	0.18	0.45	0.02	2.43	4.81	24.71

fc3 eyes open beta	0.09	0.06	0.03	0.25	1.02	3.31
fc4 eyes open beta	0.09	0.06	0.02	0.22	0.78	2.46
f3 eyes closed beta	0.11	0.09	0.02	0.46	2.57	10.76
f4 eyes closed beta	0.11	0.08	0.02	0.40	1.97	7.28
fc3 eyes closed beta	0.09	0.05	0.02	0.26	1.05	4.90
fc4 eyes closed beta	0.11	0.07	0.03	0.28	1.14	3.36
f3 eyes open gamma	0.10	0.17	0.01	0.65	2.29	6.84
f4 eyes open gamma	0.16	0.54	0.01	2.88	4.74	24.23
fc3 eyes open gamma	0.04	0.03	0.01	0.14	1.64	4.84
fc4 eyes open gamma	0.04	0.03	0.01	0.14	1.41	4.55
f3 eyes closed gamma	0.03	0.03	0.01	0.10	1.40	3.86
f4 eyes closed gamma	0.03	0.03	0.01	0.14	2.26	8.89
fc4 eyes closed gamma	0.03	0.02	0.01	0.09	1.03	2.78
c3 eyes closed gamma	0.03	0.02	0.01	0.08	0.96	3.18

Table 6.1.2.
Correlations of Critical Thinking Disposition Inventory, Cognitive Flexibility and Beta Waves (N=28)

		f3 eyes open beta	f4 eyes open beta	fc3 eyes open beta	fc4 eyes open beta	f3 eyes closed beta	f4 eyes closed beta	fc3 eyes closed beta	fc4 eyes closed beta
CCTDI total	Pearson Correlation	,007	,016	,427*	,355	,442*	,299	,349	,143
	Sig. (2-tailed)	,972	,936	,021	,059	,016	,115	,064	,460
	N	29	29	29	29	29	29	29	29
Cognitive flexibility	Pearson Correlation	,064	,224	,490**	,536**	,497**	,435*	,380*	,305
	Sig. (2-tailed)	,740	,243	,007	,003	,006	,018	,042	,108
	N	29	29	29	29	29	29	29	29

Table 6.1.3.
Correlations of Critical Thinking Disposition Inventory, Cognitive Flexibility and Frontal, Fronto Central and Central Eyes Open Gamma Waves (N=28)

		Cognitive flexibility	f3	f4	fc3	fc4	c3	c4	cp3	cp4
CCTDI total	Pearson Correlation	,724**	,019	,059	,542**	,530**	,516**	,536**	,497**	,040
	Sig. (2-tailed)	,000	,922	,761	,002	,003	,004	,003	,006	,839
	N	29	29	29	29	29	29	29	29	29
Cognitive flexibility	Pearson Correlation	1	,124	,237	,612**	,584**	,601**	,622**	,544**	,298
	Sig. (2-tailed)		,522	,216	,000	,001	,001	,000	,002	,116
	N	29	29	29	29	29	29	29	29	29

Table 6.1.4.
Correlations of Critical Thinking Disposition Inventory, Cognitive Flexibility and Tepora-Parietal, Parietal and Occipital Eyes Open Gamma Waves (N=28)

		Cognitive Flexibility	tp7	tp8	p3	p4	O1	O2
CCTDI total	Pearson Correlation	,724**	,442*	,421*	,350	,169	,169	,373*
	Sig. (2-tailed)	,000	,016	,023	,063	,381	,380	,046
	N	29	29	29	29	29	29	29
Cognitive Flexibility	Pearson Correlation	1	,462*	,402*	,377*	,093	,182	,243
	Sig. (2-tailed)		,012	,031	,044	,630	,344	,205
	N	29	29	29	29	29	29	29

Table 6.1.5.
Correlations of Critical Thinking Disposition Inventory, Cognitive Flexibility and Frontal, Fronto Central and Central Eyes Closed Gamma Waves (N=28)

		Cognitive flexibility	f3	f4	fc3	fc4	c3	c4	cp3	cp4
CCTDI total	Pearson Correlation	,724**	,535**	,503**	,502**	,395*	,468*	,506**	,430*	,458*
	Sig. (2-tailed)	,000	,003	,005	,006	,034	,010	,005	,020	,012
	N	29	29	29	29	29	29	29	29	29
Cognitive flexibility	Pearson Correlation	1	,589**	,583**	,580**	,550**	,515**	,562**	,473**	,321
	Sig. (2-tailed)		,001	,001	,001	,002	,004	,001	,010	,089
	N	29	29	29	29	29	29	29	29	29

Table 6.1.6.
Correlations of Critical Thinking Disposition Inventory, Cognitive Flexibility and Tepora-Parietal, Parietal and Occipital Eyes Closed Gamma Waves (N=28)

		Cognitive Flexibility	tp7	tp8	p7	p8	p3	p4	O1	O2
CCTDI total	Pearson Correlation	,724**	,386*	,290	,297	,353	,429*	,279	,212	,381*
	Sig. (2-tailed)	,000	,038	,126	,118	,060	,020	,143	,270	,041
	N	29	29	29	29	29	29	29	29	29
Cognitive Flexibility	Pearson Correlation	1	,461*	,377*	,370*	,430*	,524**	,500**	,161	,315
	Sig. (2-tailed)		,012	,044	,048	,020	,004	,006	,405	,096
	N	29	29	29	29	29	29	29	29	29

6.2. The Estimation of the One-Factor Confirmatory Factor Analysis

Because of the structure of the experimental design and the complex process structure of the critical analytical thinking, a huge set of test and measurement materials are conducted to the participant of this research. Before the CFA, it is used explanatory factor analysis in order to eliminate irrelevant factors when explaining the best fitted and statistically significant determinant of the components of the critical-analytical thinking procedure. After that, it is demonstrated the results of the estimation of the confirmatory factor analysis (CFA) with goodness-of-fit (fit indices). Goodness-of-fit (overall fit) of the data to the model is as very crucial as the estimation of the model parameters since bla bla

The model specifying is the most crucial part of the latent variable model and confirmatory factor analysis since statistical significance levels of the post-estimation coefficients are not enough for the model choosing. At the same time, the model chosen (in the Structural Equation level or confirmatory factor analysis) should provide better fit to the data which is statistically no worse than the other models that can be picked according to the hypothetical setup.

In accordance with the general acceptance of researchers who utilize from the structural equation modelling, there are some thresholds which was targeted for this research when fitting the indexes of the models. In this regard, it can be asserted that there are two types of goodness-of-fit indicators for continuous data. The first group indicatiors are used for the baseline comparison of the independent/original model. Namely, Indicators in this group are fit indexes cutoff levels in order to determine model fit. The other indicators in the second group are used for the comparision of the different nonnested models which try to explain the same phenomena.

In the first group of the fit indexes, there three types indicators are used which are “Chi-square ratio” which is acquired by Likelihood ratio test, “Akaike information criterion” (AIC) and “Bayesian information criterion” (BIC). Generally, Likelihood Ratio Test and Chi-square result is used for the comparison of the nested models and seeing to what extent the modified model can fit the data (model trimming/hierarchal model). If a

model has been modified and reanalyzed, this test procedure provides evidence that the modified model is statistically superior to the original model with a chi-square test. The other indicators which are used for the comparison of the different nonnested models are Akaike information criterion (AIC) and Bayesian information criterion (BIC) since the variety in the Chi-square outcomes among the models has not the possibility for the interpretation for a test statistic (68). The usage of these criteria is that the nonnested model which has smaller AIC and BIC fits better the data than the other nonnested model which has bigger AIC and BIC when explaining the phenomena through the empirical model (69). For the data fitting process, with the difference of the hypothesis testing, nonsignificant chi-square value which is produced by the model indicates that the model predictions did not significantly deviate from the actual data patern (7). Namely, the model which was produced nonsignificant chi-square fits the data pattern significantly.

In the second group of the fit indexes, Comparative Fit Index (CFI) and Root Mean Square Residuals (SRMR) are used for model fitting. They are cutoff for comparing the baseline model and data fitting. In this regard, acceptable cutoff level for the Comparative Fit Index (CFI) is greater or equal 0.95 and for the Standardized Root Mean Square Residuals (SRMR) is smaller or equal 0.08 (approximately). However, it can be asserted that smaller level of Root Mean Square Residual reflects better fit of the model to the data (69).

6.2.1. Inhibition

The hypothesis on the inhibitory function in the theoretical part was that the inhibitory is one of the main element of the cognitive control. In this regard, the measurement of the inhibitory control should be supported by the Stroop test since it provides neuropsychometric outcomes for the determination of the resistance to interference, focused attention, inhibitory control and cognitive flexibility as it was mentioned above (62). Therefore, it can be asserted the original model as part 2.1.1.1 and in the Figure 5.7.1.1.1.1 is the inhibitory control as latent variable is determined by stroop

fixing, stroop mistake, stroop time difference. Beside, however, some optimal controls (covariates) should be added to the model because of the data structure in this research since the number of observation (N=28), in some manner, can inhibit the convenient fitting to the data through maximum likelihood estimation in this process.

In Table 6.2.1.1., the original model which comes from the hypothetical setup for the estimation of the inhibitory function in terms of empirical literature is demonstrated. In the regressive analysis jargon, age and gender are used for the optimal control as covariates in order to determine the accurate effect of the sub-stroop test on the inhibitory function which is one of the latent variable that reflects the one of the executive functions in the critical analytical thinking model. Although, gender and age which is coded as cins and yas, respectively, in the data set, gender reflects statistically significant (β=-.4153594; $p<0.000$) effect on the determination of the inhibitory control in the confirmatory factor analysis (CFA).

Table 6.2.1.1: The Original Model Estimation of One Factor-Model (Model 1) for Inhibitory Function

Standardized Model Variables	Coefficients	OIM Standard Error(SE)	P>|z|
Stroop time difference <- inhibition	0.6084	0.18887121	0.001
Stroop number of errors <- inhibition	0.0561572	0.2180961	0.797
Stroop number of corrections <- inhibition	.8761816	.2248891	0.000
Stroop age<- inhibition	-.2838048	.2042997	0.165
Stroop gender <- inhibition	-.4153594	.2000247	0.038

After the estimation of the first model (Model 1) for the inhibitory function in the CFA, it should be examined the fit indices in order to determine to what extent the model fits the data through the varied the goodness-of-fit indicators.The Goodness-of-fit indicators which are used for fitting the indicies in this research, it can be examined the original model (Model 1) for the corfimatory factor analysis of the inhibitory function. In Table 6.2.1.2., CFI equals 1.000 and SRMR is 0.036. These indicators show that the model fits the data quite well. However, in Table 6.2.1.1., the outcome of the Wald Test (p-value) of the stroop mistake is 0.797 which means it is not statisticaly significant estimator for the inhibitory factor. For that reason, we change the model for adjustment by excluding stroop mistake (stroop_yanlis) and code this adjusted model as Model 2 for this part.

Table 6.2.1.2.: Fit Statistics of the Original One Factor-Model (Model 1) for Inhibitory Function

Fit Statistics	Test Statistics	Value
Likelihood ratio	Chi2(5) P>chi2	1.171 0.948
Information Criteria	AIC BIC	536.629 556.617
Baseline Comparison	CFI TLI	1.000 2.158
Size of Residuals	Standardized Root Mean Square Residual (SRMR)	0.036

For the second model for the inhibitory function (Model 2), the goodness-of-fit indicators is demonstrated in Table 6.2.1.3.. Although p-value for Model 2 is smaller that for Model 1, this level is suitable for the acceptance of good fit for the data pattern. Beside this, CFI is 1.000 (≥ 0.95) and SRMR is 0.030 (≤ 0.080) which indicate that the baseline comparison for data fitting of this model is in the acceptable level. Lastly, we can compare the AIC and BIC levels of these two models. In Table 6.2.1.4., AIC and BIC levels of Model 2 (468.776, 484.763, respectively) is smaller than of Model 1 (536.629 and 556.617, respectively). Therefore, we can assert that Model 2 has a fit statistically no worse than Model 1 and can explain better the inhibitory function than Model 1.

Table 6.2.1.3.: Fit Statistics of the Adjusted One Factor-Model (Model 2) for Inhibitory Function

Fit Statistics	Test Statistics	Value
Likelihood ratio	Chi2(2) P>chi2	0.483 0.785
Information Criteria	AIC BIC	468.776 484.763
Baseline Comparison	CFI TLI	1.000 1.462
Size of Residuals	Standardized Root Mean Square Residual (SRMR)	0.030

Table 6.2.1.4.: Model Comparison of One-Factor Models for Inhibitor Functions

	df	Chi2	AIC	BIC	SRMR	CFI
Model 1	5	1.171	536.629	556.617	0.036	1.000
Model 2	**2**	**0.483**	**468.776**	**484.763**	**0.030**	**1.000**

6.2.2.Set-shifting Ability

As it was menioned above, one of the significant executive fuction is set-shifting ability (cognitive flexibility) (8). The capacity of shifting backward and forward between various works, or mental sets is called set shifting (7).

In Part 5.7.1, the theoretical setup for set-shifting ability was that seven fundamental indicators of Wisconsin Card Sorting Test which are total errors, total answer, perseverative responses, percentage of perseverative errors, non-perseverative errors, percentage of conceptual level responses, failure to maintain set and frontal beta activities from the EEG measurement are used as the observed variable for the

determination of the setshifting ability in the latent variable model and the confirmatory factor analysis (CFA).

In the ordinary course of model estimation, we demonstrate the estimation results, Observed Information Matrix of Standard Errors (OIM SE) and p-value of estimated coefficients of the model variable in Table 6.2.2.1. The first thing which can be realized from the estimation results is that the percentage of Conceptual Level Responses (W_kavramsal_tepki_yuzde) (p-value = 0.438), open eyes left frontal beta activity (f3_ga_beta) (p-value = 0.176), open eyes right frontal beta activity (f4 eyes open beta) (p-value = 0.527), open eyes right fronto central beta activity (fc4 eyes open beta) (p-value =0.144), closed eyes left frontal beta activity (f3 eyes closed beta) (p-value = 0.523), closed eyes right frontal beta activity (f4 eyes closed beta) (p-value = 0.434) and closed eyes right fronta central beta activity (fc4 eyes closed beta) (p-value = 0.146) are higly statistically insignificant for the confirmatory factor analysis and one-factor model for set-shihfting ability.

In Table 6.2.2.2., it can be founded the fitting indicies for the original one factor-model (Model 1) for set-shifting function. We can easily see that CFI level (0.246) is higly low for the acceptable level for CFI (0.95) and SRMR (0.468) is higher in terms of acceptance level for SRMR (0.08).

Table 6.2.2.1.: The Original One Factor-Model (Model 1) for Setshifting Function

Standardized Model Variables	Coefficients	OIM Standard Error(SE)	P>|z|
WCST total answers <- setshifting	0.8705752	.0464563	0.000
WCST total errors <- setshiftinh	.925812	.0280712	0.000
WCST perseverative error percentage<- setshifting	.9882916	.0060982	0.000

WCST perseverative response <- setshifting	0.995425	0.0049363	0.000
WCST conceptual level responses<- setshifting	-.1439768	.1857996	0.438
F3 eyes open beta <- setshifting	-.2418001	.1785272	0.176
f4 eyes open beta <- setshifting	-.1183218	.1869712	0.527
fc3 eyes open beta <- setshifting	.351269	.1662809	0.035
fc4 eyes open beta <- setshifting	.2583673	.1770353	0.144
f3 eyes closed beta <- setshifting	.1194409	.187213	0.523
f4 eyes closed beta <- setshifting	.1453833	.185876	0.434
fc3 eyes closed beta <- setshifting	.3586472	.1653259	0.030
fc4 eyes closed beta <- setshifting	.257684	.1770438	0.146

Now, it can be eliminated the statistically insignificant variables in the original model in order to compare the other models which statistically no worse than the other models for fitting the data pattern.

In order to determine the best fitting model for data pattern which indicates the setshifting function, it is constructed three more models:

- The Model 2 (excluding percentage of the Conceptual Level Response, open eyes right frontal beta activity (f3 eyes open beta), open eyes left frontal beta activity (f4 eyes open beta), closed eyes right frontal beta activity (F3 eyes closed beta)

and closed eyes right frontal beta activity (f4 eyes closed beta) from the original model (Model 1))

- The Model 3 (excluding closed eyes right frontal beta activity (f4 eyes closed beta), closed eyes right fronto central beta activity (Fc4 eyes closed beta) from the Model 2)

- The Model 4 (Modification for correlated error terms of the Model 3 variables: error terms of total sum and total mistake (e. WCST total answers, e. WCST total number of errors) and error terms of total answer and percentage of perseverative mistake (e. WCST total answers, e. WCST perceverative error percentage) and error terms of closed and open eyes fronto central beta activities (e.fc3 eyes open beta, e.fc3 eyes closed beta))

In Table 6.2.2.2., we try to compare all models which have the possibility to determine the setshifting ability through the various goodness-of-fit indicators. Therefore, Model 4 is best fitted model to the data for the determination of the setshifting ability among the other models.

Table 6.2.2.2.: Model Comparison (Original, Adjusted and Modified) of One-Factor Models for Setshifting Ability

	df	Chi2	AIC	BIC	SRMR	CFI
Model 1	65	281.465 (0.000)	683.505	735.461	0.246	0.468
Model 2	20	109.378 (0.000)	402.593	434.566	0.224	0.682
Model 3	9	48.967 (0.000)	546.905	570.885	0.124	0.826
Model 4	**6**	**1.992 (0.920)**	**505.931**	**533.907**	**0.010**	**1.000**

6.2.3. Insight

In Part 5.7.1, the theoretical setup for the insight function was that eight fundamental gamma activities which are open eyes right and left frontal gamma activities (f3 eyes open gamma and f4 eyes open gamma), open eyes right and left fronto central gamma activities (fc3 eyes open gamma and fc4 eyes open gamma), closed eyes right and left frontal gamma activities (f3 eyes closed gamma and f4 eyes closed gamma) and closed eyes right and left fronto central gamma activities (fc3 eyes closed gamma and fc4 eyes closed gamma) from the EEG measurement are used as the observed variable for the determination of the insight activities in the latent variable model and the confirmatory factor analysis (CFA).

In order to find statistically significant and meaningful according to empirical literature model variables, it is estimated the the estimation results, Observed Information Matrix of Standard Errors (OIM SE) and p-value of estimated coefficients of the model variable in Table 6.2.3.1. The first thing which can be realized from the estimation results is that open eyes left frontal gamma activity (f3 eyes open gamma) (p-value = 0.432) and open eyes right frontal gamma activity (f4 eyes open beta) (p-value = 0.696) are higly statistically insignificant for the confirmatory factor analysis and one-factor model for the insight activities.

In Table 6.2.3.2., it can be founded the fitting indicies for the original one factor-model (Model 1) for the insight activities. We can easily see that CFI level (0.537) is higly low for the acceptable level for CFI (0.95) and SRMR (0.173) is higher in terms of acceptance level for SRMR (0.08).

Table 6.2.3.1.: The Original One Factor-Model (Model 1) for Insight Activities

Standardized Model Variables	Coefficients	OIM Standard Error(SE)	P>|z|
f3 eyes open gamma <- insight	.1507045	.1919739	0.432
f4 eyes open gamma <- insight	.0776048	.1989001	0.696
fc3 eyes open gamma <- insight	.6952149	.1042862	0.000
fc4 eyes open gamma <- insight	.6408057	.1250625	0.000
f3 eyes closed gamma <- insight	.9567941	.0384091	0.000
f4 eyes closed gamma <- insight	.5589747	.1364027	0.000
fc3 eyes closed gamma <- insight	.8972481	.0456756	0.000
fc4 eyes closed gamma <- insight	.5449751	.1479128	0.000

Now, it can be eliminated the statistically insignificant variables in the original model (Model 1) in order to compare the other models which statistically no worse than the other models for fitting the data pattern when determine the meaningful variable which can explain the insight activities.

For identifying the best fitted model for data pattern which indicates the insight activities, it is constructed two more models:

- Model 2: (excluding open eyes left frontal gamma activity (f3 eyes open gamma) and open eyes right frontal gamma activity (f4 eyes open gamma) from the original model (Model 1))

- Model 3: (Modification for correlated error terms of the Model 2 variables: error terms of fronte.fc4 eyes open gamma,e.fc4 eyes closed gamma & e.f3eyes closed gamma,e.fc4 eyes closed gamma & e.f4 eyes closed gamma,e.fc4 eyes closed gamma)

In Table 6.2.3.2, it is tried to detect the best-fitted model to the data among all models which have the possibility to determine the insight activities through the various goodness-of-fit indicators. In this regard, Model 3 has satisfactory overall fit among the other model in order to detect the insight activities.

Table 6.2.3.2.: Model Comparison (Original, Adjusted and Modified) of One-Factor Models for Insight Activity

	df	Chi2	AIC	BIC	SRMR	CFI
Model 1	20	88.818 (0.000)	-748.579	-716.606	0.173	0.537
Model 2	9	34.312 (0.000)	-784.170	-760.190	0.108	0.762
Model 3	**6**	**7.100 (0.312)**	**-805.381**	**-777.405**	**0.044**	**0.990**

6.2.4. Disposition

Critical thinking dispositions originated from the Delphi method used by Facione, and essential part of critical thinking (6).

California Critical Thinking Disposition Instrument (CCTDI) is the major test instrument for this research in order to measure the critical analytical thinking disposition.

The theoretical setup in Part 5.7.1, for the critical analytical thinking disposition was that eight fundamental outcome of the CCTDI which are open-mindedness (kalfikir), self-confidence (kalkendineguven), truth-seeking (kaldogruyuara) CCTDI-sum (kaltoplam), CCTDI-filter (kalfiltre) and the cognitive flexibility index (CFI) are the observed/manifest variables for the determination of the critical analytical thinking disposition in the modeling and the confirmatory factor analysis (CFA).

The estimation results, Observed Information Matrix of Standard Errors (OIM SE) and p-value of estimated coefficients of the model variable are demonstrated in Table 6.2.4.1. The first thing which can be seen from the estimation results is that all manifest variables which were added to baseline/original model are statistically significant for the confirmatory factor analysis and one-factor model for the critical analytical thinking disposition.

Table 6.2.4.1.: The Original One Factor-Model (Model 1) for Critical Analytical Thinking Disposition

Standardized Model Variables	Coefficients	OIM Standard Error(SE)	P>IzI
Cognitive flexibility <- dispostion	.7664084	.1040964	0.000
CCTDI open mindedness<- dispostion	.6418282	.1225872	0.000
CCTDI self esteem<- dispostion	.7105265	.1096034	0.000
CCTDI truth seeking <- dispostion	.7418915	.0989039	0.000
CCTDI total<- dispostion	.9038059	.0635487	0.000
CCTDI filter (Filtered according to cut off score <- dispostion	.7965975	.0895642	0.000

Although all the variables in the baseline/original model (Model 1) are statistically significant, we have to test the other models which can fit the data better than the Model 1 in order to compare the other models which statistically no worse than the other models to fit the data when detecting the meaningful variables which can explain the critical analytical disposition.

For the model which has best fitted indicies for the data which indicates the critical analytical disposition, it is built three more models:

- Model 2: (excluding CCTDI-filter from the original model (Model 1))
- Model 3: (excluding CCTDI-total from the original model (Model 1))
- Model 4 (excluding CCTDI-filter and CCTDI-total from the original model (Model 1))

In Table 6.2.4.2., it is endeavored to make firm the best fitting indicies for the model among all models which have the possibility to determine the critical analytical thinking disposition through the different goodness-of-fit indicators. Then, Model 4 has satisfactory overall fit to the data since the level of CFI for Model 4 is 1.000 which is highly satisfactory in terms of goodness-of-fit. And smallest level for BIC and AIC own to the Model 4. Lastly, SRMR level for these four model is smallest and lower level of 0.080 for the Model 4.

Table 6.2.4.2.: Model Comparison (Original, Adjusted and Modified) of One-Factor Models for Critical Analytical Thinking Disposition

	df	Chi2	AIC	BIC	SRMR	CFI
Model 1	9	18.103 (0.034)	914.496	938.476	0.059	0.901
Model 2	5	6.536 (0.258)	892.840	912.823	0.038	0.977
Model 3	5	6.487 (0.262)	695.583	715.566	0.043	0.974
Model 4	**2**	**1.184 (0.553)**	**664.854**	**680.841**	**0.027**	**1.000**

After the overall confirmatory factor analysis (CFA), we can choose the models for the executive functions which are inhibitory function and set-shifting ability, insight activities and the critical analythical thinking disposition. These models are depicted in Table 6.2.4.2. After that, we have to examine the pairwise relation between the latent variables which are estimated and measured by observed variables which were discussed above.

6.3. The Estimation of the Two-Factor Confirmatory Factor Analysis

When we look at Table 6.3.1 for the covariance analysis for pairwise relation between different factors in the hypothesized model, only the covariance of disposition and insight has consistent coefficient (p=0.017) in terms of p-value at two percent for the pairwise correlations. In this regard, we can deduce that various executive functions and insight activities which affect the critical analytical thinking are uncorrelated to each other.

Table 6.3.1.: Covariance Table for Pairwise Relation Between Various Factors in the Hypothesized Model

Covariance	Coefficient	OIM. Standard Error (SE)	P>|z|
Disposition&Inhibition	-.058592	.2218528	0.792
Disposition&Setshifting	.1235369	.2025852	0.542
Disposition&Insight	.4237712	.1781639	0.017
Inhibition&Setshifting	.3311277	.1888672	0.080
Inhibition&Insight	-.0408369	.2278146	0.858
Insight&Setshifting	.0824003	. 1931421	0.670

6.4. The Estimation of the Three-Factor Confirmatory Factor Analysis

After the estimation of the pairwise relation of the various determinants which were used for the critical analytical thinking process, successor examining question, in terms of this research, is the nature of the interraleted relationship among executive functions and insight activities which have a role in occurring the critical analytical thinking process. There are different approaches and opinions on the seperability of the interrelated relations among executive functions and insight activities in acoordance with the empirical literature. In order to examine and to test different opinions in the context of the critical thinking research, it is built three separated/extreme models which can check the best data fitting.

In order to determine the relationship mentioned above, we try to check the different models which depict the three-factor confirmatory factor analysis. When we look at the literature, we can see various research on executive functions and relationship

among each other in terms of latent variable model for the structural equation modelling jargon.

The first model which we examine is the exreme case that reflects uncorrelation for all three factors in the critical analytical thinking process. Namely, we examine that the inhibition activity, set-shifting ability and insight fuction are uncorrelated to each other when affecting the critical analytical thinking process and System-2 thinking (Model 1).

In the second model, we do not constraint any correlation relation between factors whch affect the critical analytical thinking process and allow to vary (Model 2).

In the third model, we constraint the setshifting ability and the inhibitory affect as the same factor and we do not constraint the insight activity (Model 3).

It is not required to calculate the other three-factor confirmatory factor analysis because of the results of the two-factor analysis.

In spite of the statistically significancy of the model coefficients, there is an noticeable problem in the fitting of the model to the data. Test factors of various model cannot achieve the overall fit. Therefore, we can only determine the better model between different alternatives

	df	Chi2	AIC	BIC	SRMR	CFI
Model 1	99	161.649 (0.000)	170.601	241.208	0.168	0.848
Model 2	96	158.940 (0.000)	173.892	248.496	0.149	0.847
Model 3	97	165.962 (0.000)	178.914	252.185	0.188	0.832

The more probable alternative is that the executive functions and insight activities are uncorrelated to each other when determining the critical analytical thinking process.

6.5. The Structural Equation Modeling of the Critical Analytical Thinking Process

After the modelling in which we determined the factors that estimate the latent variables of the critical analytical thinking process in terms of confirmatory factor analysis, we can construct some important structural models in order to explain the critical analytical thinking process and System-2 thinking. In terms of this research, one of the most significant problem is the exiguity of the amount of observation for psychometric tests. However, the hardship of carrying out EEG measurement and its standards, the current numbers of the observation for this research can be regard as suitable in accordance with the literature. Therefore, we have to limit structural model building in some manner. In this regard, there are two main structural models which can explain the critical analytical thinking process. The first one is the main model which reflects the path diagram from the cognitive reflection to critical thinking disposition through the insight activity. The second structural model demonstrates the indirect relation between insight activity and set-shifting functions.

6.5.1 Cognitive Reflection and Critical Analytical Thinking

One of the significant results of this research is that the path through begins from the cognitive reflection to the cognitive disposition through insight activity can reflects the process of the critical analytical thinking. Therefore, we construct a structural equation model which demonstrates this theoretical model. The results are shown in Table 6.5.1.1. as it can be seen that all coefficients in the model statistically significant. Likewise, there is no need to additive modification to the model since all MI values less than 3.842.

In accordance with the results in the table, the cognitive reflection affects the cognitive disposition through insight activity in the indirect path as structural equation modelling jargon. The cognitive reflection affects the insight activity with 0.4414 magnitude and the insight activity affects the coginitive disposition with magnitude 0.559.

Table 6.5.1.1.: Standardized Regression Coefficients for Structural Equation Models with Critical Analytical Thinking Disposition (N=28)

Standardized Model Variables	Coefficients	OIM Standard Error(SE)	P>|z|
Structural			
Insight <-crt	.4414857	.1559803	0.005
disposition <-insight	.5590559	.1541861	0.000
Measurement			
fc3 eyes open gamma <- insight	.6444916	.1340312	0.000
fc4 eyes open gamma <- insight	.8259512	.084196	0.000
f3 eyes closed gamma <- insight	.62038	.1303755	0.000
f4 eyes closed gamma <- insight	.5632003	.1518335	0.000
fc3 eyes closed gamma <- insight	.7280852	.1068629	0.000
fc4 eyes closed gamma <- insight	.7418975	.1130613	0.000
Cognitive Flexibility <- disposition	.9497096	.0582705	0.000
CCTDI open mindedness <- disposition	.607621	.1309917	0.000
CCTDI self esteem <- disposition	.7481704	.0955299	0.000
CCTDI truth seeking <- disposition	.7290904	.0978997	0.000

	df	Chi2	AIC	BIC	SRMR	CFI
Model 1	37	30.530 (0.765)	-64.322	-13.699	0.075	1.000

6.5.2. Insight Activity and Set-Shifting Function

The last part of the structural equation modelling for this research is the investigation of the indirect relation between insight activity and setshifting ability. As it can be seen in Table 6.5.2.1. all estimated coefficients are statistically significant. And beside this, in part 6.3, setshifting ability and insight activity have not direct relation in terms of causative effection to each other.

Accorting to the Table 6.5.2.1. all estimated coefficients are statistically significant and to the last part of the table, the structural model can fit the data properly.

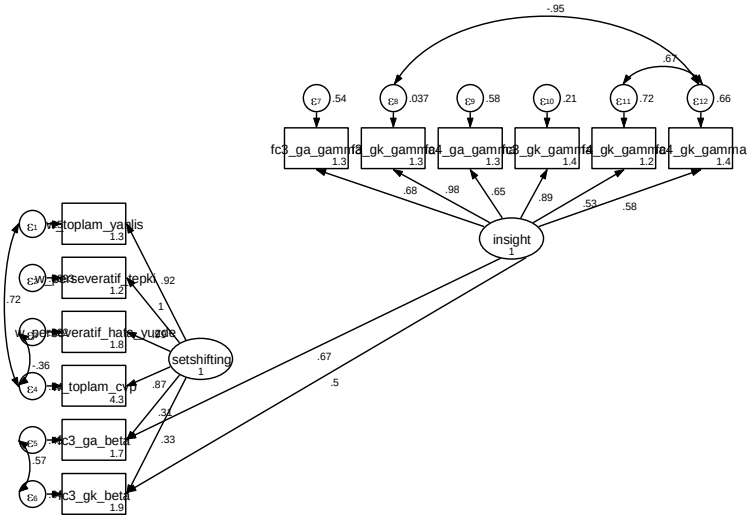

Figure 6.5.2.1.: The Diagram Demonstrates the Relation Between Setshifting and Insight Activity

Table 6.5.2.1.: Standardized Regression Coefficients for Structural Equation Models for Indirect Effect of Insight Activity (N=28)

Standardized Model Variables	Coefficients	OIM Standard Error(SE)	P>|z|
Measurement			
WCST total number of errors <- setshifting	.9228132	.0289502	0.000
WCST perseverative response <- setshifting	.9953398	.0073159	0.000
WCST perseverative error percentage <- setshifting	.9891152	.0081846	0.000
WCST total number of answers <- setshifting	.8703086	.0482373	0.000
fc3 eyes open beta <- setshifting insight	.3139325 .6708653	.1281032 .1031848	0.014 0.000
fc3 eyes closed beta <- setshifting insight	.3328384 .5035379	.1468429 .1348241	0.023 0.000
fc3 eyes closed gamma <- insight	.6774546	.1038134	0.000
f3 eyes closed gamma <- insight	.9812882	.0302114	0.000
fc4 eyes open gamma <- insight	.6482064	.1151877	0.000
fc3 eyes closed gamma <- insight	.8881659	.0431619	0.000
f4 eyes closed gamma <- insight	.5320886	.1395946	0.000
fc4 eyes closed gamma <- insight |	.5823075	.1385246	0.000

	df	Chi2	AIC	BIC	SRMR	CFI
Model 1	37	67.055 (0.029)	-313.672	-256.387	0.086	0.946

According to these results, we can conclude that the insight activity affects the setshifting ability thorugh the frontal beta activity as an indirect manner.

7. DISCUSSION

Critical thinking has two components: skills and dispositions. In this study, I found significant correlations between critical thinking dispositions, cognitive flexibility and EEG frontal and fronto central Gamma activity.

In the model I tried to explain critical thinking dispositions with two pathways. The first explanation is the following; System 2 thinking predicts critical thinking dispositions throught insight latent variable.

Studies on thinking and reasoning suggest two different cognitive pathways. System 1 can be counted as older in evolutionary perspective and the other animals also have it. System 2 is more developed and special to human, enables us to think hypothetical and abstract terms. However it might be slower and have restricted capacity (70). Goel et al proposed that there are two separable organizations in the brain for deductive reasoning. When there is a belief-logic conflict condition, right inferior/middle prefrontal cortex activated. This might mean that the prefrontal area functions as reasoning mechanism or conflict resolution. Also there are some hemispheric differences. For logical reasoning, right hemisphere is needed sometimes but it is not enough alone. On the other hand left hemisphere is essential and sufficient (71).

In our study, System 2 thinking was measured by Cognitive Reflexion Test (CRT). On the other hand, participants had their EEG recordings in the absence of stimulus or a reasoning task. Even so, CRT scores predict insight latent variable which consists of cognitive flexibility inventory and EEG frontal and centro-frontal eye open gamma frequencies. This result can lead the conclusion that individuals who tend to think reasonably, have higher gamma levels in their frontal cortex and this leads insightful thinking.

Lau et al found anterior cingulate and left lateral prefrontal cortical activation in fMRI during Aha! reaction. Those areas also associated with cognitive conflict. The Aha! reaction or insight could be described as a brief time period of remarkable thinking which occur with an immediate alteration in one's mindset, produces a solution to a difficult problem (72).

Insight is not a process; it is an immediate conscious accessibility of a solution. The associated neural activity -immediate burst of gamma band activity- does not occur following solutions, the beginning of this activity corresponds with the conscious availability of solutions (73). Dopamine enhances self-awareness and also enhances gamma waves via medial prefontal/anterior cingulate cortex (74) Thus, dopamine levels might be higher in the people who tend to have insightful thinking characteristics and this might lead increased gamma band activity in their frontal cortex. This literature might explain our model; since system 2 thinking is more complicated and related to the Aha! moment, it might predict the insight latent variable.

Cognitive flexibility is the ability to restrict a dominant reaction when it is not optimum or suitable solution to a problem and capacity to reach more remote alternatives. (75). Cognitive flexibility (measured by cognitive flexibility inventory) fit the model perfectly for explaining the insight latent variable with frontal and centra-forntal gamma activities. This is not surprising in the sense that cognitive flexibility serves better problem solving capacity and this could lead insightful thinking.

These complex higher level thinking might require insight or the Aha! Moment as the model suggests. Frontal gamma activation and cognitive flexibility shapes a persons critical thinking tendencies. If cortical neurons activate in synchrony in gamma band, people become aware of their representations. Luo et al (2009) tested the hypothesis and found that increased gamma band event related synchronization is associated with consciousness (76). In the study, higher gamma band activity was seen without visual or

auditory stimuli. This would be a sign that, people who have tendency to think criticaly have higher gamma band activation during mind-wandering.

The second pathway that tries to explain critical thinking dispositions is executive functions. In the model only inhibition and set shifting were used to represent executive functions. All tasks would need the use of working memory ability and there is no single neuropsychological test to completely catch the executive component of working memory (37). Thus I did not use a specific task to measure working memory capacity in the experiment while explaining the relationship between executive functions and critical thinking.

Diamond suggested that executive functions (working memory, inhibitory control, and cognitive flexibility) predicts higher level executive functions like reasoning, problem solving and planning (8). However in the model, we could not prove this association while considering critical thinking dispositions as higher-level executive function. The reason would be either because of the limited sample size, or because those executive functions could be a base for critical thinking skills rather than dispositions.

This model could be healpful for teaching critical thinking since it gives information about the process. Critical thinking teaching methods would begin with practices to increase system 2 thinking. After learning consciously thinking slow before deciding, they would focus on cognitive flexibility and realizing alternatives. This process might eventually increase gamma band activity. All of these predicts tendency to think criticaly. In educational setting, the focus is on teaching skills. However skills are useless without dispositions. Considering this pathway, the quality and effectiveness of education programs related to critical thinking would increase.

On the other hand, since the model shows that critical thinking dispositions are related to frontal brain activity, any pathology could distract the critical thinking abilities. For example decreased gamma band activity were seen in patients with schizophrenia

(77). Decreased cognitive flexibility is associated with obsessive and depressive thinking (38). Thus a new important research question emerges: whether practicing critical thinking abilities can be protective for some neurological or psychological disorders.

There are some limitations of the study. Although sample size is appropriate for an EEG research, structural equation modelling needs larger sample size and some problems related to fitting was observed. For future studies, the study would be replicated with increased sample size.

Second limitation could be focusing only dispositions while studying critical thinking. Some tests for measuring skills could be added the study and executive functions would have relationship with skills rather than dispositions.

Last but not least, although Cognitive Reflexion Test is generaly used to measure system 2 thinking, only using 3 question could be inadequate to measure system 2 thinking. Also some participants stated since its popularity, they knew the questions and answers before we asked them. For future studies, better assessment could be preferred for system 2 thinking.

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9. APPROVAL OF ATHICAL COMMITTEE

T.C.
İSTANBUL MEDİPOL ÜNİVERSİTESİ
Girişimsel Olmayan Klinik Araştırmalar Etik Kurulu Başkanlığı

E-İmzalıdır

Sayı : 10840098-604.01.01-E.12586 31/05/2017
Konu : Etik Kurulu Kararı

Sayın Şerife Leman KÖYBAŞI

Üniversitemiz Girişimsel Olmayan Klinik Araştırmalar Etik Kuruluna yapmış olduğunuz "Analitik düşünme, yürütücü işlevler ve elektrofizyolojik korelatları" isimli başvurunuz incelenmiş olup etik kurulu kararı ekte sunulmuştur.

Bilgilerinize rica ederim.

Prof. Dr. Hanefi ÖZBEK
Girişimsel Olmayan Klinik Araştırmalar
Etik Kurulu Başkanı

Ek:
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BAŞVURU BİLGİLERİ	**ARAŞTIRMANIN AÇIK ADI**	Analitik düşünme, yürütücü işlevler ve elektrofizyolojik korelatları			
	KOORDİNATÖR/SORUMLU ARAŞTIRMACI UNVANI/ADI/SOYADI	Şerife Leman Köybaşı			
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	Belge Adı	Tarihi	Versiyon Numarası	Dili
Değerlendirilen Belgeler	ARAŞTIRMA PROTOKOLÜ/PLANI	24.05. 2017		Türkçe ☒ İngilizce ☐ Diğer ☐
	BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU	24.05.2017		Türkçe ☒ İngilizce ☐ Diğer ☐
Karar Bilgileri	**Karar No: 194**	**Tarih: 31/05/2017**		
	Yukarıda bilgileri verilen Girişimsel Olmayan Klinik Araştırmalar Etik Kurulu başvuru dosyası ile ilgili belgeler araştırmanın gerekçe, amaç, yaklaşım ve yöntemleri dikkate alınarak incelenmiş ve araştırmanın etik ve bilimsel yönden uygun olduğuna **"oybirliği"** ile karar verilmiştir.			

İSTANBUL MEDİPOL ÜNİVERSİTESİ GİRİŞİMSEL OLMAYAN KLİNİK ARAŞTIRMALAR ETİK KURULU	
BAŞKANIN UNVANI / ADI / SOYADI	Prof. Dr. Hanefi ÖZBEK

Unvanı/Adı/Soyadı	Uzmanlık Alanı	Kurumu	Cinsiyet		Araştırma ile ilişki		Katılım *		İmza
Prof. Dr. Şeref DEMİRAYAK	Eczacılık	İstanbul Medipol Üniversitesi	E ☒	K ☐	E ☐	H ☒	E ☐	H ☒	
Prof. Dr. Hanefi ÖZBEK	Farmakoloji	İstanbul Medipol Üniversitesi	E ☒	K ☐	E ☐	H ☒	E ☒	H ☐	
Yrd. Doç. Dr. Sibel DOĞAN	Psiko-onkoloji	İstanbul Medipol Üniversitesi	E ☐	K ☒	E ☐	H ☒	E ☒	H ☐	
Yrd. Doç. Dr. Devrim TARAKCI	Ergoterapi	İstanbul Medipol Üniversitesi	E ☒	K ☐	E ☐	H ☒	E ☒	H ☐	
Yrd. Doç. Dr. İlknur KESKİN	Histoloji ve Embriyoloji	İstanbul Medipol Üniversitesi	E ☐	K ☒	E ☐	H ☒	E ☒	H ☐	
Yrd. Doç. Dr. Mehmet Hikmet ÜÇIŞIK	Biyoteknoloji	İstanbul Medipol Üniversitesi	E ☒	K ☐	E ☐	H ☒	E ☒	H ☐	

* :Toplantıda Bulunma

10. CURRICULUM VITAE

Personal Information

Name	Şerife Leman	Surname	KÖYBAŞI
Birth Place	Selçuklu-KONYA	Birthdate	03.07.1992
Nationality	T.C.	Identification Number	53317584084
E-mail	s.lemankoybasi@gmail.com	Phone number	05069827520

Level of Education

	Graduated Institution Name	Graduation Year
PhD	-	-
Master	-	-
Undergraduate	Boğaziçi University	2015
Highschool	Guventas Anatolian Highschool	2010

Job Experience

	Görevi	Kurum	Süre (Yıl - Yıl)
1.		-	-
2.		-	-
3.		-	-

Foreign Languages	Reading*	Speaking*	Writing*
English	Excellent	Good	Excellent
Arabic	Good	Good	Average
Korean	Good	Good	Average

* Evaluate as excellent, good, average, beginner.

Language Proficiency Results								
KPDS	YDS	IELTS	TOEFL IBT	TOEFL PBT	TOEFL CBT	FCE	CAE	CPE
-	88,75	-	-	-	-	-	-	-

If there are more than one succesful exam, all the results should be written.

KPDS: Kamu Personeli Yabancı Dil Sınavı; YDS: Yabancı Dil Bilgisi Seviye Tespit Sınavı; IELTS: International English Language Testing System; TOEFL IBT: Test of English as a Foreign Language-Internet-Based Test TOEFL PBT: Test of English as a Foreign Language-Paper-Based Test; TOEFL CBT: Test of English as a Foreign Language-Computer-Based Test; FCE: First Certificate in English; CAE: Certificate in Advanced English; CPE: Certificate of Proficiency in English

	Quantitative	Equal Weight	Verbal
ALES Score	83,52354	85,82487	75,75644
(Diğer) Puanı			

Computer Knowledge

Program	Skill
Microsoft Office Program	Excellent
SPSS	Excellent
EEGLAB	Average
Brain Vision Analyzer	Average
Matlab	Beginner

- Evaluate as excellent, good, average, beginner.

International and National Academic Publishing/Papers/Certificates/Awards/Others

PUBLICATIONS

Yang, T., Penton, T., Koybasi, S.L., & Banissy, M. J. (2017). Social perception and aging: The relationship between aging and the perception of subtle changes in facial emotion and identity. Acta Psychologia, 179, 23-29.

POSTERS

Köybaşı, Ş. L., Uysal, R., Sezgin, F. B., Çiçek, G., Avşaroğlu, E. A., Yıldırım, E., Hanoğlu, L. The relationship of consolidation and forgetting on long Term: Normative Study of Öktem-SBST, Poster presentation at 14th National Neuroscience Congress, Ankara, Türkiye, 2016

Sezgin, F.B., Ergen, G., Kahraman, T., Uysal, R., Köybaşı, Ş.L., Düz Ö.A., Birday E., Hanoğlu L. The relationship between Clinicaly isolated syndrome and Long Term Memory, Poster presentation at 14th National Neuroscience Congress, Ankara, Türkiye, 2016

SCHOLARSHIPS

Erasmus higher education work placement and internship scholarship (2014)

Tubitak National Scholarship Programme for MSc Students (2016)

CERTIFICATES

17. Ulusal Psikoloji Kongresi (17th National Psychology Congress) Boğaziçi University, TPD 25.04.12-28.04.12

Aile Çocuk Şiddet Konferansı (Family Child Violence Conference) Boğaziçi University, 27.05.14

Face to face with psychoanalysis Summer School The British Psychoanalytic Association, 04.07.14-06.07.14

Boğaziçi University Art Sertificate, 2015