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T.C.
BAHCESEHIR UNIVERSITY
GRADUATE SCHOOL OF EDUCATION
THE DEPARTMENT OF COGNITIVE NEUROPSYCHOLOGY

NEURAL DYNAMICS OF MEMORY-BASED DECISION-MAKING
AND EPISODIC FEELING OF KNOWING IN THE DECISION-RE-
DECISION PARADIGM: AN ERP STUDY

MASTER'S THESIS
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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

NEURAL DYNAMICS OF MEMORY-BASED DECISION-MAKING AND EPISODIC FEELING OF KNOWING IN THE DECISION-RE-DECISION PARADIGM: AN ERP STUDY

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M.S., Cognitive Neuropsychology

Supervisor: Prof. Dr. Metehan Irak

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Investigating the neural dynamics of memory-based decision-making (Yes/No) and the feeling of episodic knowing judgment (FOK) using different task paradigms is essential for the memory and metacognition literature. The current study aims to examine the neural mechanisms of memory-based decision-making and the FOK judgment through the episodic memory paradigm, which includes the decision-re-decision phase, a new paradigm in the literature. The episodic memory task consists of five phases. In line with the aim of the study, the focus was on the third and fourth phases, named the decision and re-decision phases and evaluating memory-based decision-making and FOK judgment. Seventy individuals aged between 18-27 were included in the study. During the decision and re-decision phases, the neural dynamics of memory-based decision-making and FOK judgment were investigated contingent on behavioral response percent, reaction time, visual analyses of ERP topography and ERPs' amplitude values. Behavioral findings demonstrated that the reaction time (RT) of inconsistent "Yes," "No," and "FOK" responses was significantly longer than the RT of consistent responses. Additionally, the visual analysis results indicated the differences in the ERP topography of memory-based decision-making and metacognitive judgments. Finally, consistent with our expectations, regional and hemispheric comparisons of the decision type main effect were found significant for "Yes", "No," and "FOK" responses. Findings demonstrated significant amplitude differences between decision and re-decision stages in some N100, P200 components

and late time windows (400-650ms and 651-900 ms). The results are discussed in the light of memory-based decision-making and metacognition literature.

Keywords: Decision making, Feeling of knowing, Metamemory, Episodic memory, Event-related potentials, Re-decision.



ÖZ

KARAR-YENİDEN KARAR PARADİGMASINDA BELLEK TEMELLİ KARAR VERME VE OLAYSAL BİLME HİSSİ KARARLARININ NÖRAL DİNAMİKLERİ

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Bellek temelli karar verme (Evet/Hayır) ve olaysal bilme hissi (BH) kararlarının farklı görev paradigmalarını kullanılarak nöral dinamiklerinin araştırılması bellek ve üstbellek literatürü için oldukça önemlidir. Mevcut çalışmanın amacı, bellek temelli karar verme ve BH kararının nöral dinamiklerini epizodik bellek paradigması aracılığıyla incelemektir. Bu paradigma, literatürde yeni olan karar-yeniden karar aşamasını içermektedir. Epizodik bellek görevi beş aşamadan oluşmaktadır. Çalışmanın amacına uygun olarak, üçüncü ve dördüncü aşamalara, yani karar ve yeniden karar aşamalarına odaklanılarak bellek temelli karar verme ve BH yargıları incelenmiştir. Çalışmaya 18-27 yaş aralığındaki yetmiş katılımcı dahil edilmiştir. Karar ve yeniden karar aşamalarında bellek temelli karar verme ve BH yargısının nöral dinamikleri, davranışsal yanıt yüzdelerine, tepki süresine, ERP topografisinin görsel analizlerine ve ERP genlik değerlerine dayalı olarak incelenmiştir. Davranışsal bulgular, tutarsız "Evet", "Hayır" ve "FOK" yanıtlarının tepki süresinin tutarlı yanıtların süresinden önemli ölçüde daha uzun olduğunu göstermiştir. Ayrıca, görsel analiz sonuçları, bellek temelli karar verme ve üstbilişsel değerlendirmelerin ERP topografisindeki farklılıklara işaret etmiştir. Son olarak, beklentilerimize uygun olarak, bölgesel ve hemisferik karşılaştırmalarda "Evet", "Hayır" ve "BH" yanıtları için karar türü ana etkisi anlamlı bulunmuştur. Bulgular, "Yes", "No" ve "BH" yanıtlarının bazı N100, P200 bileşenlerinde ve bazı geç zaman pencerelerinde (400-

650 ms ve 651-900 ms) karar ve yeniden karar aşamaları arasında genlik değerlerinin anlamlı derecede farklılaştığını göstermiştir. Sonuçlar, bellek temelli karar verme ve üstbilişsel süreçler literatürü bağlamında tartışılmıştır.

Anahtar kelimeler: Karar verme, Bilme hissi, Üstbellek, Olaysal bellek paradigması, Olay-ilişkili potansiyeller, Yeniden karar





To all individuals who ignited my curiosity and
open new rooms in my mind with
every tiny spark of ideas...

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ABBREVIATIONS

AIC	Anterior Insular Cortex
BA	Broadmann's Area
dACC	Dorsal Anterior Cingulate Cortex
EEG	Electroencephalography
EOL	Ease of Learning
ERP	Event-related Potentials
FH	Fluency Heuristic
fMRI	Functional Magnetic Resonance Imaging
FOK	Feeling of Knowing
FPCN	Frontoparietal Control Network
G	Goodman-Kruskal Gamma
JOL	Judgements of Learning
IFPC	Lateral Frontopolar Cortex
LPC	Late Positive Component
LTM	Long-term Memory
M.I.N.I	The Mini-International Neuropsychiatric Interview
MCI	Mild Cognitive Impairment
ms	Milliseconds
mPFC	Medial Prefrontal Cortex
MTL	Medial Temporal Lobe
NSW	Negative Slow Wave
PCC	Posterior Cingulate Cortex
PFC	Prefrontal Cortex
RH	Recognition Heuristic
RJR	Recall-judge-recognition
RK	Remember/Know
ROC	Receiver Operating Characteristic
RTs	Reaction Times
SN	Salience Network
TBB	Take-the-best

Chapter 1

Introduction

Memory is posited as a cognitive mechanism encompassing the intricate processes of encoding, storing, and retrieving information when necessary (Wheeler, 2005). When examining the historical trajectory of memory research, it becomes evident that Hermann Ebbinghaus's contributions are widely acknowledged as pioneering scientific investigations on memory. The prevailing notion of a particular memory state in long-term memory was subsequently challenged by Endel Tulving's seminal proposal introducing two distinct sub-types of memory, namely episodic memory and semantic memory (Solso, Maclin, & Maclin, 2005; Tulving, 1972; Tulving, 1993). According to Tulving's seminal work (1993), episodic memory, a neurocognitive process, represents a memory system facilitating the recollection of past events. Retaining these personally experienced events relies on the mechanism of "autobiographical reference" (Tulving, 1972; Tulving, 1993). Episodic memory distinguishes itself from semantic memory regarding content and susceptibility to forgetting (Solso, Maclin, & Maclin, 2005). Throughout one's lifetime, semantic memory displays relatively lower activation levels than episodic memory, preserving semantic information over time (Solso, Maclin, & Maclin, 2005). Conversely, episodic memory engages in a continuous process of re-encoding and storage, rendering the information more susceptible to alterations (Solso, Maclin, & Maclin, 2005). The ongoing retrieval of this information, supported by the hippocampus structure (Squire & Zola-Morgan, 1991), plays a pivotal role in memory recall.

Recognition memory refers to the ability to identify as familiar a stimulus that has been encountered previously. The processes of familiarity and recollection, which are postulated by the dual-process theory and underlie the performance of recognition memory, have been empirically demonstrated using diverse experimental procedures, including the process-dissociation procedure (Jacoby, 1991), the remember/know procedure (Tulving, 1985), and receiver operating characteristic (ROC) procedures (Yonelinas, 1994). Specifically, the remember-know procedure, developed by Tulving (1985), aims to distinguish between distinct types of recognition. Tulving (1985)

argued that "Recollection can be associated with the conscious re-experiencing of the episodic features of the study event, termed autonoetic consciousness," while familiarity is characterized by a more noetic consciousness. In other words, subjects acknowledge the study words but do not re-experience specific knowledge about to the study event (Tulving, 1985). In summary, recollection entails the retrieval of precise contextual details originating from the period in which an event was initially encoded, and it is distinguished within recognition assessments by its discernible differentiation from a non-specific perception of familiarity (Yonelinas, 2002).

Furthermore, Tulving (2002) also emphasizes the temporal aspect of our long-term memory. According to Tulving (2002), in addition to recalling past events, we can mentally travel in time by envisioning ideas for the future. Based on this perspective, we can assert that in addition to remembering things we have previously experienced (retrospective memory), there is a temporal dimension of long-term memory (LTM) that involves remembering information related to accomplishing a planned goal in a future time (prospective memory).

1.1 Memory-based Decision Making

Imagine yourself in right in the middle of a highway in the busy city. You are trying to reach point A, and at your exact location, the road splits into two. With limited time to make a quick decision and unable to use navigation due to your phone running out of battery, there is only one thing left for you to do: make a decision based on the information stored in LTM. You can utilize the information about the city map from your long-term memory, recalling moments when you have previously traveled this road, to make an informed decision.

Decision-making refers to the process of selecting an option from the available alternatives based on an individual's experiences and knowledge. To characterize the process of decision-making, a simplistic approach is proposed. This approach, known under the general term "cognitive heuristics," has been highlighted to represent rational methods that reflect everyday life (Gigerenzer, Hertwig & Pachur, 2011; Gigerenzer & Goldstein, 2011). Take-the-best (TTB), introduced by Gigerenzer and Goldstein (1996), is an important seminal method. The logic of the TTB heuristic involves examining the most relevant features retrieved from LTM during a decision-making process, and once discrimination can be made among these features, such as when one

object is recognized, the search for features in LTM is halted, and a decision is made. One of the most well-known heuristic approaches is the recognition heuristic (RH), suggesting that we utilize our brain's extensive capacity for recognition. The recognition heuristic was proposed by Goldstein and Gigerenzer (2002) in their studies utilizing the two-alternative forced-choice task. In this task, participants were required to decide which of the two presented cities had a larger population (e.g., İstanbul and Ankara). According to this recognition heuristic, the process of making a recognition decision concludes when the most relevant features are retrieved from LTM, examined, and when a feature is classed higher than an unrecognized feature. Otherwise, when the participant is equally remembered both presented stimuli (Istanbul, Ankara) and needs to determine which stimulus has a higher population, then precisely at this point, they need to develop an alternative approach. As addressed in the dual process model, familiarity is also regarded as a heuristic method. The fluency heuristic (FH) was characterized by Schooler and Hertwig (2005). The fluency heuristic utilizes the speed of retrieving information from memory as a basis for memory-based decision-making.

Various behavioral procedures are employed to investigate the role of information stored in long-term memory in a memory-based decision-making process. One such procedure is the remember/know (RK) (Tulving, 1985; Gardiner, 1988). In this procedure, participants are asked to provide a "Remember" response if they recall the presented stimulus from among the stimuli they learned previously or during the encoding phase. If they believe the stimulus is among the learned stimuli but cannot recall it specifically, they are instructed to provide a "Know" response. Remember responses correspond to the recollection, while Know responses represent familiarity. Furthermore, Yonelinas' (2002) study utilizing the old/new procedure demonstrated the involvement of recollection and familiarity processes in determining whether a stimulus is old or new. Specifically, it was found that the accuracy of old/new recognition was higher for Remember responses compared to Know responses.

However, at the same time emphasis has shifted from the idea that RK judgments are based on recollection and familiarity to highlighting memory strength using the signal detection theory that single-processes approach of recognition memory. According to the signal detection theory, RK responses reflect different degrees of memory strength rather than different memory processes (Donaldson, 1996). The signal detection theory states that Remember responses indicate a high

level of memory strength, while Know responses suggest that the memory strength is not strong enough to provide a remember responses. Notwithstanding, the signal detection theory has been criticized for distinguishing not between recollection and familiarity, but rather between strong and weak traces of the remembered material (Swets & Green, 1978; Wixted & Mickes, 2010).

1.2 Neural Basis of Memory-Based Decision Making

Studies conducted with various imaging techniques, using both patient and healthy samples, provide us with information about the neural foundations of memory-based decision making. The importance of the medial temporal lobe (MTL) function is well-known in the retrieval of episodic memory. Rugg and Vilberg's (2013) study points to the role of a broad cortical network within the MTL. This cortical network includes the hippocampus, parahippocampal gyrus, retrosplenial/posterior cingulate cortex (PCC), precuneus, medial prefrontal cortex (PFC), and angular gyrus. It is emphasized that these regions play a role in supporting the representation and retrieval of episodic memories in the brain. These findings are consistent with previous comprehensive studies conducted with healthy older adults and patients with memory complaints. Also, Wolk and colleagues (2008; 2011) emphasize the stronger association between the hippocampus and recollection, while familiarity is shown to be associated with the perirhinal and lateral entorhinal cortices within the extrahippocampal MTL structure. The results support the studies that provide evidence of the specific impairment in familiarity processes caused by damage to the perirhinal cortex, while indicating that impairment in the hippocampus alone does not affect familiarity processes (Sauvage et al., 2008; Barker & Warburton, 2011). In addition to the structures within the MTL, the activation of lateral and medial prefrontal regions, as well as parietal regions, is known to be involved in the processes of attention, monitoring, and confirmation related to the retrieval of episodic memories (Yonelinas et al., 2005; Mecklinger & Jäger, 2009; Euston et al., 2012).

Furthermore, high spatial resolution imaging techniques, event-related potentials (ERP) obtained using the Electroencephalography (EEG) technique, which has a high temporal resolution, also provide valuable evidence regarding familiarity and recollection. Smith's findings (1993), among the earliest studies providing evidence for familiarity and recollection, suggest that recollection is more associated with the late parietal old/new effect, while familiarity is associated with the early mid-

frontal old/new effect (also known as FN400 component). The early mid-frontal old/new effect is observed around 300-500 ms after stimulus presentation. During this time window, more prominent ERP deflections are found for old stimuli compared to new stimuli. Recent studies help to understand that the FN400 component, which is negative at 400 ms on the mid-frontal electrodes, is an indicator for recognition memory, and these studies provide a deep understanding of familiarity and recollection processes (Czernochowski, Mecklinger, & Johansson, 2009; Curran, 2010; Voss & Federmeier, 2011; Stróżak, Abedzadeh & Curran, 2016). In Curran's study (2010), a manipulation that reduces the recollective experience was applied, this manipulation reduced recollection, and this was especially seen in the late parietal; On the other hand, these manipulations were found to have no effect on familiarity and amplitude of the FN400 component.

The late parietal old/new effect is observed around 400-800 ms after stimulus presentation. More positive-going waveforms for old stimuli emerge during this time range. Indeed, the late parietal old/new effect is also referred to as the late positive component (LPC). It is characterized by having a maximum degree specifically at the left parietal electrode, compared to the electrodes located in the right and middle regions (Rugg et al., 1998; Curran 2004). The findings from the imaging studies mentioned above have also been supported by studies using the EEG technique. For instance, Düzel and colleagues (2001) observed an early mid-frontal old/new effect in a patient with limited damage to the hippocampal region but preserved other MTL structures. In contrast they did not observe the late parietal old/new effect typically associated with recollection. The study by Hoppstädter et al. (2015) made a significant contribution to the literature by examining the electrophysiological and functional magnetic resonance imaging (fMRI) data relationships in an old/new paradigm with word lists. According to the findings of the study, in relation to familiarity, activation in the right dorsolateral prefrontal cortex and right intraparietal sulcus was found to be associated with the amplitude value of the early mid-frontal old/new effect. On the other hand, recollection was characterized by its association with the amplitude value of the late parietal old/new effect observed in the right posterior hippocampus, parahippocampal cortex, and retrosplenial cortex.

Hypotheses and supporting findings suggest the differential involvement of familiarity and recollection in item recognition memory and associative recognition

memory. According to this approach, item recognition is supported by familiarity and recollection, whereas associative recognition is solely supported by recollection. Yonelinas' study demonstrates that item recognition exhibits curvilinear and asymmetrical ROCs, while associative recognition shows almost linear ROCs. These findings indicate a selective benefaction of recollection to associative recognition memory (Yonelinas, 1997; 2002). However, the argument that familiarity does not support associative recognition is debatable. For example, in the study on associative recognition memory conducted by Zhang et al. (2015), participants were presented with a list of related word pairs and unrelated word pairs, and they were asked to determine whether these pairs were old, rearranged, or new. The results indicate the presence of an early mid-frontal old/new effect specifically for associative words, distinguishing them from non-associative words. When examining the parietal old/new effect, it is observed that this effect has a higher amplitude in the left parietal electrode, specifically for associative word pairs compared to unrelated word pairs. It provides evidence for the role of both familiarity and recollection in the associative recognition (see also Quamme, 2004; Rhodes & Donaldson, 2007).

Therewithal, the effectiveness of encoding a piece of information also influences the recognition process. As stated in the study by Rugg and Curran (2007), the strategy employed by participants during encoding (deep or shallow) does not affect the early mid-frontal old/new effect responses. However, the left parietal positivity serves as an index of deep encoding. It has been proposed that the deeper encoding reflected in the LPC serves as a precursor to the interpretation of performance during the retrieval stage, such that if a participant has knowledge about the source of the stimulus in a correct old responses, a more positive going LPC is observed compared to the situation where the participant lacks this source information (Yonelinas, 2002; Woroch & Gonsalves, 2010).

Rogers and colleagues' study (2016) provides compelling evidence for the memory-based decision-making process. By incorporating a linear model for drift rates in the diffusion model, the researchers presented evidence of the impact of components emerging at approximately 400 ms on frontal electrodes and around 600 ms on parietal electrodes on the decision process. It is suggested that the early component, associated with familiarity processes, does not index the decision process, but rather the late component associated with recollection. The late component is involved in a memory-based decision-making process by providing evidence to assess

and predict the strength or weakness of a presented item compared to others. On the other hand, the early component does not provide such discriminatory information. Although researchers acknowledge the importance of gathering information about the characteristics of presented materials before the decision-making process begins, they emphasize that the crucial factor during the decision-making moment is determining, discriminating, and acquiring the relevance of information to the decision at hand (Roger et al., 2016).

In summary, the familiarity process, characterized by the retrieval of information specific to the presented stimulus but not specific episodic details, is primarily associated with an early component that emerges in the frontal region at approximately 400 ms. On the other hand, the recollection process, involving a form of mental time travel and awareness, and requiring the recall of episodic details within a spatial and temporal context, is associated with a late component that emerges in the parietal region at approximately 600 ms. The role and involvement of the parietal late component is emphasized in memory-based decision-making processes.

1.3 Feeling of Knowing Judgment

The feeling-of-knowing (FOK) judgment, as an index of the broad concept of metacognition, which reflects the process of monitoring and controlling one's own cognitive system, pertains to the individual's feeling of being able to remember a currently unrecalled item in the future (Nelson & Naren, 1990; 1994; Koriat, 2016). The initial studies on FOK judgments were pioneered by Hart (1965). Hart (1965) examined metacognitive processes using the recall-judge-recognition (RJR) paradigm. Within this paradigm, participants are asked to answer questions about either semantic, general knowledge (e.g., Which is the highest mountain in the world?) or episodic, personally experienced information (e.g., associative word-pairs) (Pannu & Kaszniak, 2005). In the groundbreaking study by Nelson and Narens (1990), it was proposed that monitoring, an inherent aspect of metacognitive processes, can be both retrospective and prospective; retrospective monitoring occurs after the completion of an event, followed ending retrospective monitoring, the activation of prospective monitoring. Nelson and Narens (1990) investigate prospective monitoring using three categories: ease of learning (EOL), judgements of learning (JOL) and feeling-of-knowing (FOK).

Within the FOK paradigm, participants provide FOK judgments for items that cannot be recalled from memory during the retrieval phase following the learning phase. They are asked to determine whether they will be able to remember or not remember the stimuli that are currently unrecalled, if presented among various options in the future. In general, participants are asked to rate their FOK judgments on a Likert-type scale. These Likert-type scales can vary in different studies, ranging from 6-point Likert scales (Irak et al., 2019; Irak, Soylu & Yavuz, 2023) to 3-point or even fewer points (Baran et al., 2009; Güler et al., 2020). After reporting their FOK judgments on the Likert-type scale, participants proceed to the recognition task where they attempt to identify the target stimulus among the presented alternatives. In some studies, in the literature, participants are only asked to make FOK judgments for stimuli they falsely and don't remember, while in other studies, to enhance the resolution of FOK judgments, participants are required to make FOK judgments for both correctly and falsely remembered stimuli (all-item FOK) (see also Baran et al., 2009; Boduroglu et al., 2015; Schwartz, Boduroğlu & Tekcan, 2016; Güler et al., 2020). The Goodman-Kruskal Gamma (G) is a nonparametric correlation and it is a frequently used calculation method to assess the accuracy of individuals' FOK judgments. It provides an accuracy score based on the relationship between participants' FOK judgments and recognition performance (see Nelson & Narens, 1990).

Two primary hypotheses in the literature address the generation of FOK judgments, namely cue-familiarity and accessibility. According to the cue-familiarity view, higher familiarity of the cue stimulus is associated with improved recall and recognition performance, and it is proposed that FOK judgments will be higher for cues with high familiarity (Reder, 1987; Perrotin et al., 2007; Irak et al., 2019). Metcalfe and colleagues (1993) emphasize that FOK judgments are contingent upon cue familiarity, which serves as an indirect assessment. As the familiarity of the cue increases, FOK judgments also increase, even in the absence of actual retrieval. This heuristic approach proves particularly valuable in situations where quick judgments based on external features of the question are required (Reder & Ritter, 1992).

Conversely, the accessibility model suggests that FOK judgments depend on the quantity and accessibility of information about the stimulus in memory (Perrotin et al., 2007; Koriat, 1995, 2016; Irak et al., 2019). As per the framework proposed by Koriat (2007), FOK judgments are influenced by the accessible information stored in memory, and monitoring occurs as a subsequent process following retrieval. In

essence, individuals can assess the presence of a target item in memory by utilizing the available partial information about that item and proceed with the search accordingly. Within this model, Koriat (1995) asserts that the correspondence between FOK judgments and actual memory performance, referred to as FOK accuracy, is influenced by both accurate and inaccurate partial information.

Integrating these two perspectives, a dual-process model is proposed, wherein the familiarity of the stimulus is initially evaluated, followed by the assessment of information accessibility during the retrieval process (Koriat & Levy-Sadot, 2001). The influence of accessibility becomes particularly evident in cases of heightened familiarity, thereby indicating a moderating role of familiarity in the overall process of accessibility. While both familiarity and accessibility are essential constituents of the process, the presence of heightened familiarity enhances the impact of accessibility (Koriat & Levy-Sadot, 2001).

Hart (1965) suggests that memory monitoring encompasses the intrusive and descriptive processes bridging recall and recognition. It is evident that memory performance relies not only on memory itself but also on the involvement of control and monitoring processes inherent in metamemory (Mazzoni & Nelson, 2014). Understanding the relationship between memory systems and metamemory is a fundamental objective for researchers investigating metacognitive processes. During the process of making an FOK judgment, participants provide insights into information that has not yet been accessed, and this paradoxical circumstance has held significant significance in memory research by shedding light on the boundaries of conscious recollection experiences (Koriat, 2000).

1.4 Neural Basis of Feeling of Knowing Judgment

Researchers investigating FOK judgments in individuals with neurodegenerative diseases or lesions, and healthy samples have endeavored to comprehend the neural mechanisms underlying this cognitive process. Studies involving individuals with Korsakoff's Syndrome and amnesic patients, has highlighted the interaction of the frontal lobe and MTL structures with FOK judgments (Pannu & Kaszniak, 2005). Comparative investigations involving these patient populations have provided evidence that amnesic patients exhibit impairments in FOK judgments, despite intact executive functions, implicating memory processes in this task (Johnson et al., 2000; Pannu & Kaszniak, 2005). On the other hand, in the investigation conducted by Modirrousta and colleague (2008), the role of the medial

prefrontal cortex (mPFC) in the process of FOK judgment was examined. The study involved a patient with 5 mPFC damage and 19 healthy participants, who were subjected to a face-name episodic memory task. This task encompassed six stages, including the learning phase, JOL phase, recall phase, confidence rating, FOK judgments, and recognition phase (Modirrousta & Fellow, 2008). The findings revealed that even when the participants' memory performance was comparable, the disruptive impact of mPFC on FOK persisted. Thus, the involvement of mPFC structures in the FOK process was evident, irrespective of individuals' memory performance (Modirrousta & Fellow, 2008). Neuroimaging studies have further investigated the memory and executive function abilities of individuals, providing support for the accessibility account and emphasizing the involvement of the fronto-temporal network in FOK processes. The findings reveal distinct relationships between memory and executive function performance and the FOK process, depending on the participants' disease diagnosis. FOK accuracy is found to be correlated with memory performance measures among individuals with mild cognitive impairment (MCI), whereas it is associated with executive function performance measures among control participants. In conclusion, these results underscore the significance of the fronto-temporal network in episodic FOK processes (Perrotin et al., 2007). In addition to the recognized role of the fronto-temporal network as a determinant of episodic FOK judgments, recent studies have highlighted the significance of the rostrolateral and dorsolateral regions of the prefrontal cortex (PFC) (Fleming, Huijgen & Dolan, 2012) as well as the involvement of the frontoparietal control network (FPCN) and the salience network (SN) (Fleming et al., 2012; Qui et al., 2018). The importance of these structures is emphasized in relation to their involvement in metacognitive processes during decision-making.

The nature of the paradigm used greatly influences the FOK judgment. While regions such as the left prefrontal cortex, anterior cingulate cortex, and left parietal lobe exhibit neural activity during FOK judgments, different brain regions come into play when using a paradigm involving semantic or episodic material. In the context of this study, focusing on episodic FOK judgments within our experimental paradigm, the specific brain areas and ERP components observed were examined. Reggey, Zuckerman, and Maril (2011) reported increased neural activity in the left middle temporal gyrus, the cuneus, and the posterior cingulate in their neuroimaging studies. These structures are also associated with episodic memory retrieval processes,

although they are not solely responsible for FOK judgments. Furthermore, the prefrontal cortex, which plays a critical role in determining the accuracy of FOK judgments, should be emphasized (Reggey et al., 2011; Fleming, Huijgen & Dolan, 2012).

When examining the literature on ERPs in studies investigating FOK judgments, it is evident that there has been a particular focus on the P200, N200, and P300 components (Paynter et al., 2009; Irak et al., 2019; Irak, Soylu & Yavuz, 2023). In the pioneering study conducted by Paynter and colleagues (2009), which is considered one of the seminal works in this field, the findings from using mathematical problems as stimuli revealed that participants who engaged in monitoring rather than recalculating their answers exhibited significant activations in the frontal P200 and frontocentral P300 components of the ERPs. These ERP components were hypothesized to reflect the assessment of familiarity levels and were interpreted as potential indicators of the involvement of prospective monitoring processes.

Upon reviewing more recent studies, a series of investigations conducted by Irak and colleagues have provided detailed insights into the neurobiology of episodic FOK. In a study conducted by Turan, Irak, and Soylu (2017), FOK judgments were evaluated using a semantic memory paradigm, revealing the presence of the P200 component in parietal and occipital regions, as well as the N200 component in fronto-central electrodes. In addition to these findings, examining ERP components associated with high and low FOK judgments has gained importance. The study by Irak et al. (2019) offers evidence supporting the differentiation of high and low FOK judgments at the ERP level. The researchers demonstrated that the amplitude of the P200 component is higher in frontal and fronto-central regions for high FOK judgments. Conversely, considering low FOK judgments, the amplitude of the N200 component is higher in parietal regions. The findings suggested that the FOK judgment is linked to the engagement of a significantly wider network rather than the functioning of a particular region. The P200 component is associated with various cognitive processes such as short-term and working memory, repetition priming, familiarity effects, and implicit memory (Luck, 2005; Waninger et al., 2018). Moreover, it is proposed to contribute to the assessment of the stimulus' familiarity and accessibility during the FOK decision-making process (Irak et al., 2019). Furthermore, Irak, Soylu, and Turan (2020) investigated the ERP components of both retrospective (JOL) and prospective (FOK) metacognitive judgments using a face-word pair task. Compared

with low FOK, the N100, P100, P200, and P300 components exhibited higher amplitudes for high FOK judgments. Lastly, in a recent study conducted by Irak and colleagues (2023), examining event-related potentials of both retrospective (retrospective confidence judgments: RCJs) and prospective (FOK) metacognitive judgments in both semantic and episodic memory tasks, it was emphasized that retrospective and prospective metacognitive judgments reflect distinct cognitive processes. The researchers provided evidence suggesting that FOK judgments reflect a domain-specific process, whereas RCJ responses reflect a domain-general process.

In summary, it is emphasized that FOK judgment is sensitive to the type of task used and is a domain-specific process (Irak et al., 2023). When examining ERP findings, it is observed that the P200 and P300 components observed in early time windows, especially in frontal and fronto-central areas, are associated with the monitoring process and guide metacognitive decisions (Paynter et al., 2009; Błaszczak, Czepionka & Klimek-Jankowska, 2018; Irak, Soylu & Turan, 2020). The FOK judgment appears to be associated with the involvement of a significantly wider network rather than the functioning of a specific region.

1.5 Goal of the Study

The question regarding the distinguishability of memory-based decision-making and metacognitive processes has garnered increasing significance. There is evidence suggesting the involvement of shared neurobiological structures between FOK judgments and the retrieval processes of episodic memory. Current studies also indicate the possibility of distinction between metacognitive processes and memory-based decision-making processes (Qui et al., 2018; Jiang et al., 2022). However, studies that demonstrate the distinct neural basis of these two processes are quite limited. And there is currently no study in the literature that examines and compares the temporal dynamics of these two processes. Investigating the temporal dynamics of memory-based decision making and metacognitive processes can provide further insights into the existing perspectives in the literature. And also, the results to be obtained within the scope of this study can provide us with important information about the dynamics of decision making and metacognitive processes in the processes of encoding, storing and retrieval of information. Understanding the neural basis of the memory-based decision making and metacognitive processes will provide crucial insights for professionals working with patients experiencing neurodegenerative and

psychiatric symptoms, as well as individuals struggling with decision-making difficulties that arise during healthy aging. This knowledge will contribute to the development of effective cognitive rehabilitation aimed at addressing decision making challenges.

Qui and colleagues (2018) promoted an innovative decision-re-decision paradigm to demonstrate the dissociation between metacognitive processes and decision-making, as in Theory 1. Theory 1 is based on evidence suggesting that damage to the PFC, which plays a significant role in metacognitive processes, can impair metacognitive monitoring while leaving the decision-making process unaffected (Fleming et al., 2014; Bor et al., 2017; Qui et al., 2018). Additionally, Qui and colleagues (2018) address the opposing view proposed in Theory 2, which suggests that the decision-making process serves as a determinant for metacognitive processes and can rely on accumulated evidence. Evidence accumulation models (EAMs), which have been prominent in the scientific literature for a considerable duration, have been proposed as valuable tools for comprehending the underlying decision-making processes. According to this model, it is claimed that the decision-making process is triggered by the accumulation of evidence ("drift rate") in favor of the alternative options offered and when this accumulation reaches a sufficient level (decision threshold) (Ratcliff et al., 2016; Evans & Wagenmakers, 2019). Part of the researchers who propose Theory 2 see decision-making and metacognitive processes as interconnected and emphasize that metacognition is not dependent on a different nervous system to monitor and control the decision-making process (see van Den Berg et al., 2018). At this point, the decision/re-decision paradigm that Qui and colleagues used in their research paves the way for us to gain a deep perspective on decision making and metacognitive processes.

Researchers (Qiu et al., 2018; Jiang et al., 2022) show that the distinction between metacognition and decision-making becomes apparent within the decision-re-decision paradigm, as it allows participants to reconsider their decisions in the same context. This opportunity for re-decision is considered critical in initiating the metacognitive processing. Researchers report a specific neural underpinning for metacognitive processes, as suggested in Theory 1. It is pointed out that metacognitive processes are more involved in the re-decision phase, where the responses given in the previous decision phase, the confidence in these decisions and the uncertainty about the decision are reviewed. Decision confidence is a belief about that one's own

decision is correct. On the contrary, decision uncertainty acts as a regulatory cue to enhance one's decision-making process, even in the absence of external feedback (Smith et al., 2003). Decision uncertainty represents the inverse of decision confidence. The existence of decision uncertainty during the re-decision phase is considered very important for the initiation of metacognitive processing (Fleming et al., 2012; Jia et al., 2020; Qiu et al., 2018; Jiang et al., 2022). To such an extent that elevated decision uncertainty elicits a retrospective examination of the decision, leading to a meta-cognitive control and monitoring mechanism that facilitates the exploration of additional decision alternatives (Nelson & Narens, 1990; Qiu et al., 2018; Jiang et al., 2022).

Qui and colleagues (2018) highlight that the dorsal anterior cingulate cortex (dACC) and anterior insular cortex (AIC) regions, responsible for metacognitive monitoring and control, detect and encode uncertainty during decision-making. Additionally, the ventral striatum (VS) and the lateral frontopolar cortex (IFPC) play a role in cognitive control. It is emphasized that the information from the VS affects the cognitive control process in which the IFPC plays a role. VS and IFPC especially monitor and control the inferior frontal junction (IFJ), which shows neural activity in the decision-making system. Researchers point to the existence of "a closed-loop system". It is emphasized that the neural activity of the regions in the "a closed-loop system" has a positive correlation with decision uncertainty. The findings of a recent study conducted to investigate the neural underpinnings of metacognition and mentalization processes are also consistent with this information. Jiang and colleagues (2022) used the random dots motion task to measure metacognitive processes, and after the participants answered about the direction of motion of the dots, they were asked to rate their uncertainty about this decision on a 4-point Likert-type scale. Researchers have linked metacognitive processes to decision uncertainty. The involvement of the dACC, IFPC, and precuneus regions has been indicated in relation to metacognitive processes (Jiang et al., 2022).

There have been numerous studies by using high spatial resolution methods on FOK and memory-based decision-making (Qiu et al., 2018; Jiang et al., 2022; Fleming et al., 2014; Bor et al., 2017). According to the existing literature, it is emphasized that cortical structures including the dACC (Brodmann's Area (BA) 24), AIC (BA 13), VS (BA 25), IFPC (BA 10), and inferior frontal junction (IFJ, BA 9) (Strotzer, 2009; Koessler et al., 2009; Scrivener & Reader, 2022) play a crucial role in the decision-

making process, specifically in metacognitive monitoring and control, as well as the detection and encoding of uncertainty processes. But it is clear that there is not enough research using high temporal resolution techniques to serve a deeper understanding of these findings. Although the temporal resolution of the EEG technique is high, it is not possible to map the electrodes to directly collect electrophysiological data from a specific brain region, as this electrical activity data collected through the electrodes represents a collective signal from underlying neural activity in multiple brain regions. Hence, it is crucial to interpret the findings obtained through high-resolution imaging techniques in conjunction with high-temporal resolution techniques to ensure a comprehensive analysis.

Based on the information obtained from the literature, the main purpose of this study is to investigate whether metacognitive judgment (FOK) and memory-based decision making (Yes/No) has similar or distinct neural basis. In order to seek an answer to this question, BAU Brain and Cognition Research Lab team developed a project supported by the TÜBİTAK 1001 program and created an experimental paradigm (Irak, 2020). Within the scope of the episodic memory task based on learning word pairs, we examined the ERP components of the participants' memory-based decision making (Yes/No) and metacognitive judgments (FOK) in the decision-re-decision phases. Thus this thesis is a part of above mentioned project.

Furthermore, as indicated in the literature summarized above, the impact of decision uncertainty on metacognitive processes cannot be denied. Within in the scope of this study, it will be discussed uncertainty through consistent (same response among decision and re-decision) and inconsistent (different responses among decision and re-decision phases) responses. Because it is known that the presence of uncertainty, if given a chance to give the answer again, this causes to monitor and explore other alternatives and the change of decision can be observed (Wan et al., 2016). Examining the consistency or inconsistency of memory-based decisions and metacognitive judgments can provide us with detailed information about the nature of these notions. In this context, one of the important objectives in the current study is to investigate the effects of uncertainty on FOK judgments and memory-based decision making, at the amplitude level of ERPs.

Although primary goal of this thesis was not investigating the effects of hemispheric differences and electrode location/site and on ERPs, we also tested these two variables. Additionally, within the scope of the present study, behavioral data has

been analyzed, including reaction time, consistent and inconsistent responses among two phases of the task (decision and re-decision).

1.6 Hypotheses of the Study

- 1) The ERP topography of memory-based decisions (Yes/No) and metacognitive judgments (FOK) differ. In memory-based decision making, individuals evaluate whether the information is currently present in their memory (related to recollection, rather than familiarity) (Tulving, 1985; Gardiner, 1988). On the other hand, metacognitive judgments (FOK), it is a decision about whether they will be able to select the relevant stimulus from the options presented in the future, even if the relevant information is not currently present in their memory (not recollective experience). Although both processes rely on information in long-term memory (LTM), FOK judgment, unlike memory-based decision making, is a prospective judgment (Nelson & Naren, 1990).
- 2) Amplitude values of ERPs during “Yes”, “No” and “FOK” response different at decision and re-decision phase according to electrode sites (see “Theory 1” in Qui et al., 2018). The amplitude difference between the decision and re-decision phases of metacognitive judgments (FOK) is more pronounced compared to memory-based decisions (Yes/No).
- 3) The reaction times (RTs) for consistent "Yes", "FOK", and "No" responses during the re-decision phase exhibit distinguishable patterns compared to the RTs for inconsistent "Yes", "FOK", and "No" responses.

Chapter 2

Method

2.1 Participants

70 subjects (51 females) who aged between 18 and 27 ($M = 21.42$, $SD = 1.99$), participated in this study. Behavioral data and EEG recording was collected from all participants at Bahçeşehir University Brain and Cognition Research Laboratory. Participants were right-handed, native Turkish speaker and with having normal or corrected-to-normal vision university students. In order to control the inclusion criteria, information about whether the participants had a history of neurological disorder, psychiatric disorder, COVID-19, and drug use affecting the central nervous system was obtained through the pre-interview, and participants who did not have such a history were included in the study. Informed consent was provided to the participants in a manner approved by the Bahçeşehir University Ethics Committee. Participants who completed all phases of the experiment were given a 50 TL gift card.

2.2 Materials

2.2.1 The mini-International neuropsychiatric interview (M.I.N.I.). The M.I.N.I. is originally developed by Sheehan et al., (1998). The Turkish version of M.I.N.I. adapted by Engeler (2004) was used in this study. A diagnostic interview, the M.I.N.I. was developed for use in clinical psychiatry and research settings for Axis I psychiatric disorders in DSM-IV and ICD-10. Individuals are asked 21 screening questions structured for each psychiatric disorder. If the answer to these questions is “Yes”, questions in the submodules are asked to the individuals to make a more detailed inquiry about this disorder. The application time is approximately 20 minutes.

2.2.2 Experimental paradigm. The design of the episodic memory task utilized in this experiment was developed based on previous studies and was further refined using the findings obtained from a pilot study conducted prior to the main experiment (e.g., Hart, 1965, Irak et al., 2019, Wahlheim et al., 2019, Irak, 2020). Figure 1 presents the flow diagram depicting the various phases of the episodic memory task. The task comprises five distinct phases: word-pairs learning, judgment of learning (JOL), decision/confidence, re-decision/re-confidence, and recognition in this thesis, the third (decision) and fourth stages (re-decision) were analyzed.

In the learning phase, 94 word-pairs were presented in the center of the screen. Each word-pair was displayed for 3 seconds, with one-second intervals between stimuli. The participants were instructed to memorize these word-pairs to the best of their ability. The selection of words was made from the list of high-frequency words derived from the Word Frequency Dictionary of Written Turkish by Göz (2003). To mitigate the potential influence of the primacy/recency effect, the first two word-pairs and the last two word-pairs among the total of 94 word-pairs were designated as buffers and excluded from the subsequent analysis. In the second phase, the participants were presented with a screen showing only the word on the left of the word pair shown during the learning phase, and participants were instructed to make a JOL decision using the "Definitely not able to remember", "Uncertain", "Definitely able to remember" buttons within 3 seconds. During the decision/confidence phase, solely the right word was presented on the screen for 3 seconds, encompassing a total of 135 word-pairs. This set comprised 45 novel word-pairs in addition to the word-pairs acquired during the initial phase. Participants were instructed to indicate their recollection of the counterpart word for the displayed word by utilizing the mouse to click on the corresponding buttons labeled "Yes", "No", or "FOK" (currently unable to remember, but future recall is anticipated with a cue)." Subsequently, participants were requested to express their confidence level regarding their decision by selecting from the options displayed on the screen, namely "Sure," "Uncertain," or "Not sure.". In the subsequent re-decision/re-confidence phase, participants were directed to repeat the decision and confidence assessment for each word-pair, engaging in a thorough reevaluation of their previous responses. Finally, during the recognition phase, participants were instructed to find correct word among the options presented on a screen where only the left-hand word pair was displayed within 4 seconds. A set of 90 word pairs that were presented to the participants during the learning phase formed the basis for the subsequent statistical analyses.

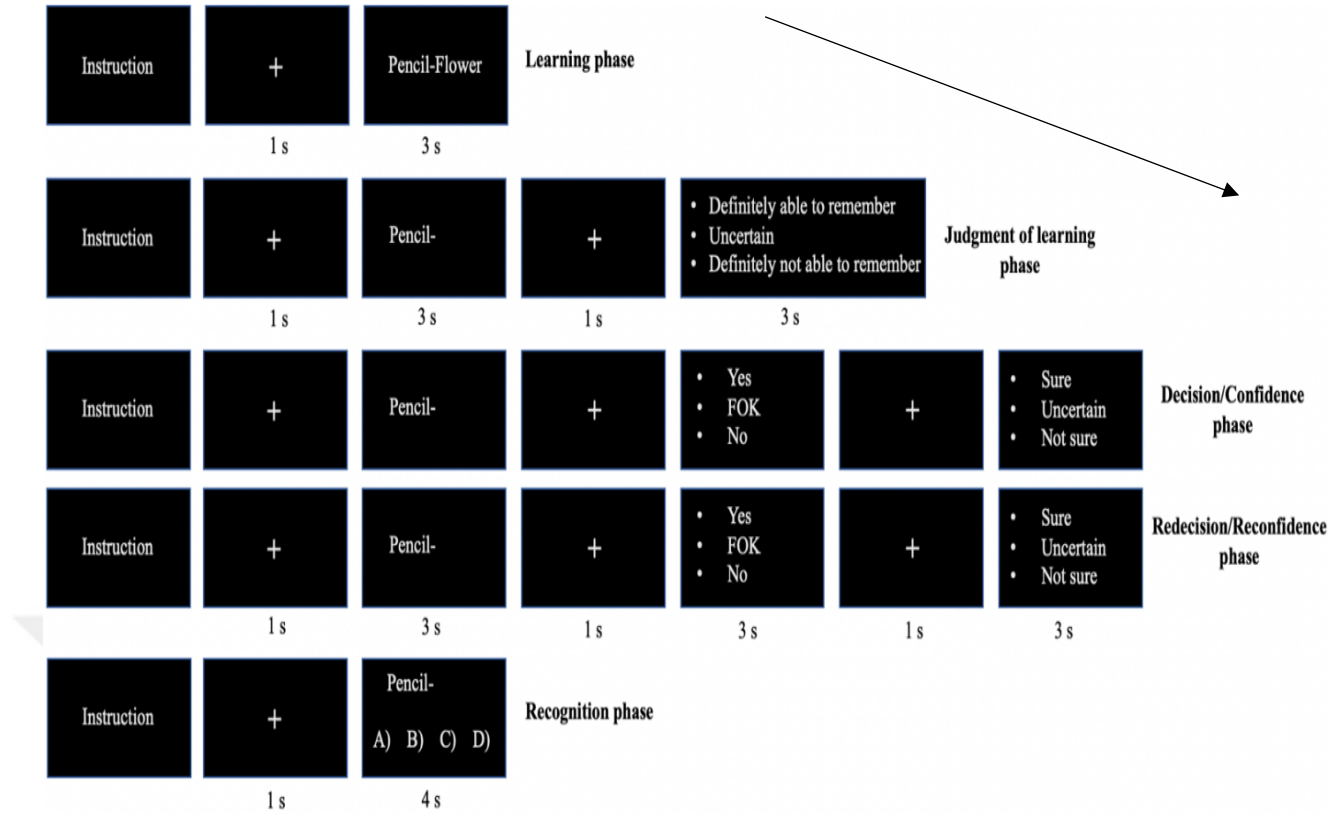


Figure 1. Experimental task was used in the study.

2.3 EEG Recording and Preprocessing

The episodic memory task was performed in a soundproof and electrically shielded room (Faraday room), and ERP and behavioral data of the participants were recorded during the experiment. The stimulus presentation, recording, storage, and analysis were carried out utilizing a 64-channel EEG system equipped with NeuroScan 4.51 software and Curry 8. The EEG activity was captured using a 64-channel electrode field embedded within elastic Quick-caps from Neuromedical Supplies, Compumedics, Inc., Charlotte. The positioning of the electrodes followed the international 10-20 system guidelines established by Klem et al. (1999). For the recording of EOG activity, two bipolar channels were placed at the temporal sides of the eye, and an additional two electrodes were positioned above and below the left eye. In addition, two electrodes were placed on the right and left mastoids (M1/M2). All EEG electrodes were initially referenced online to a vertex electrode and later re-referenced offline to the tied mastoids. To capture the EEG/EOG signals, amplification was performed using the Synamp RT amplifier at AC mode from Neuroscan, Compumedics, Inc., Charlotte. The signals were recorded at a sampling rate of 1000 Hz. The amplification was accompanied by low-pass filtering at 0.15 Hz, high-pass

filtering at 100 Hz, and a notch filter at 50 Hz to remove any power line interference. The impedance of the EEG electrodes was diligently maintained below 5 k Ω to ensure accurate recordings. The EEG data sets of all participants were preprocessed using Curry 8 and NeuroScan 4.51 software from Neuroscan, Compumedics, Inc., Charlotte. To reduce computational demands, the data was down-sampled to a frequency of 250 Hz. Artifact reduction was performed in two phases. The first phase involved the removal of artifacts related to eye movements such as blinks and saccades, as well as different types of noise including sharp-signal, linearity, and sinusoidal noise. Vertical (VEO) and horizontal (HEO) EEG/EOG channels exceeding a threshold of ± 200 were automatically detected and eliminated. In the second phase of artifact rejection, trials containing various patterns of saccades identified in the horizontal EOG channel were manually discarded. Segments with an interval of -100 ms preceding the onset and 1000 ms following the onset were rejected. To compute event-related potentials (ERPs), the artifact-free segments were subjected to baseline correction using a 100 ms pre-stimulus period. Subsequently, averaged amplitude values were calculated for the decisions associated with each response.

2.4 EEG Analysis

In the current study, the evaluation of the analyzed ERPs was performed by calculating the mean amplitude (μV) for each subject over five-time windows. During the decision phase, peak amplitude readings were performed for frontal and central electrodes in the time intervals of 50-135 ms (N100), 130-200 ms (P200), and for parietal electrodes in the time intervals of 60-180 ms (N100), 120-180 ms (P200). On the other hand, in the re-decision phase, peak amplitude readings were performed for frontal and central electrodes in the time intervals of 75-120 ms (N100), 125-190 ms (P200). For parietal electrodes, these values were obtained from the time intervals of 60-110 ms, 130-180 ms, 60-110 ms (N100), and 115-235 ms, 185-240 ms, 115-235 ms (P200) (respectively for Pz, P1, P2). In the late time window, mean amplitude were performed for all electrodes in the time intervals of 400-650 ms and 651-900 ms, both during the decision and re-decision phases. Additionally, for frontal electrodes only, mean amplitude readings were performed in the time interval of 250-500 ms. Mean amplitude values, and onset latency were calculated for answers acquired from the “Yes”, “No” and “FOK” responses in both decision and re-decision phase. Total of

nine electrodes namely F1, Fz, F2, C1, Cz, C2, P1, Pz and P2, were included statistical analyses.

2.5 Procedure

Prior to starting data collection, a pilot study was done. A total of 14 participants, aged between 18 and 25, were recruited for the pilot study. Based on the findings of the pilot study, the task was enhanced by revising the number of stimuli and adjusting the time intervals.

Prior to commencing the data collection phase, a pilot study was conducted to assess the feasibility of the experiment. This involved recording behavioral and electrophysiological data, as well as administering a demographic information form, a neurological checklist, and the M.I.N.I. questionnaire. It was checked whether the criteria for inclusion in the experiment were met. All participants were warned about various factors that could be confounding variables (sleep, caffeine consumption, etc.) during the experiment. Prior to their participation in the experiment, each participant was required to provide their informed consent by signing a consent form. The episodic memory task was structured using the C# programming language. Throughout the experiment, stimuli were presented on a Windows 10 computer equipped with a 29-inch monitor, while participants were seated in a fixed chair positioned at an equal distance from the monitor. Before the commencement of each phase, the researcher provided a briefing to the participants, instructing them to provide their responses using the mouse. The entire experiment, including the setup time for EEG recording with the electro-cap, typically lasted approximately two hours. Upon completion of the experiment, a comprehensive explanation regarding the study's purpose was provided to the participants. As a gesture of appreciation, gift cards were presented to those participants who successfully completed all the experimental phases.

Chapter 3

Results

Prior to conducting statistical analyses, the dataset was carefully examined to identify any missing values or outliers (Tabachnick and Fidell 2007). The results section of the study was partitioned into two parts, namely behavioral and ERP results.

3.1 Behavioral Results

Predominantly, the analysis focused on the percentage and mean values about the responses of each decision type during the decision and re-decision phases. The results show that participants exhibited the following responses percent during the decision phase: 27.74% for “Yes”, 36.50% for “FOK”, and 34.68% for “No”, to the total 90 words they were learned. On the other hand, in the re-decision phase, the corresponding responses distribution was 26.28% for “Yes”, 29.95% for “FOK”, and 43.07% for “No” (see Table 1). Pre, paired samples t-test analysis was conducted to compare the "Yes," "FOK," and "No" responses separately between the decision and re-decision phases. The analysis revealed a statistically significant difference between the decision and re-decision phases for “YES”, "FOK" and "No" responses, indicating a notable distinction (see Table 2).

Additionally, a paired t-test was employed to compare of reaction times (RTs) between "Yes," "FOK," and "No" responses individually during both the decision and re-decision phases. The analysis results indicate that there is no significant difference in RTs for the "Yes" answer between the decision and re-decision phases ($t(69) = 1.24, p > .05$). However, there is a significant difference in RTs for the "FOK" ($t(68) = 2.40, p < .05$) and "No" ($t(69) = 3.61, p < .05$) response between the decision and re-decision phases. The mean RTs for the "FOK" and "No" responses during the decision phase are significantly higher than the re-decision phase (see Table 3).

Furthermore, participants consistently selected for the “Yes”, “FOK” and “No” responses in both the initial decision and subsequent re-decision phases, accounting for 22.65%, 20.22%, 28.38% of answers (referred to as consistent response), respectively, whereas 5.09%, 16.28%, 6.30% of answers reflected a discrepancy, with participants indicating “Yes”, “FOK” or “No” in the decision phase but not in the re-decision phase (referred to as inconsistent response), respectively (see Table 1, Figure 2 and 3). Besides, a paired sample t-test was performed to examine whether there are

significant differences in RTs during the re-decision phase for consistent and inconsistent "Yes", "FOK", and "No" responses. The analysis results demonstrate a statistically significant difference in RTs for the "Yes", "FOK", and "No" responses between consistent and inconsistent responses ($t \geq -4.12$, $p = .001$) (see Table 4). The results indicated that participants spent significantly less time during the re-decision phase to make consistent responses compared to inconsistent responses across all response types (see Table 3).

Table 1

Statistical Values for "Yes", "FOK", "No" Responses in Decision and Re-decision Phases

	YES			FOK			NO		
	%	<i>M</i>	<i>SD</i>	%	<i>M</i>	<i>SD</i>	%	<i>M</i>	<i>SD</i>
Decision Phase	27.74	24.97	16.73	36.50	32.85	10.47	34.68	31.21	17.03
Re-decision Phase	26.28	23.65	16.47	29.95	26.95	12.94	43.07	38.77	20.68
Consistent Response	22.65	20.38	14.93	20.22	18.2	10.34	28.38	25.54	16.83
Inconsistent Response	5.09	4.58	4.53	16.28	14.65	5.99	6.30	5.67	4.66

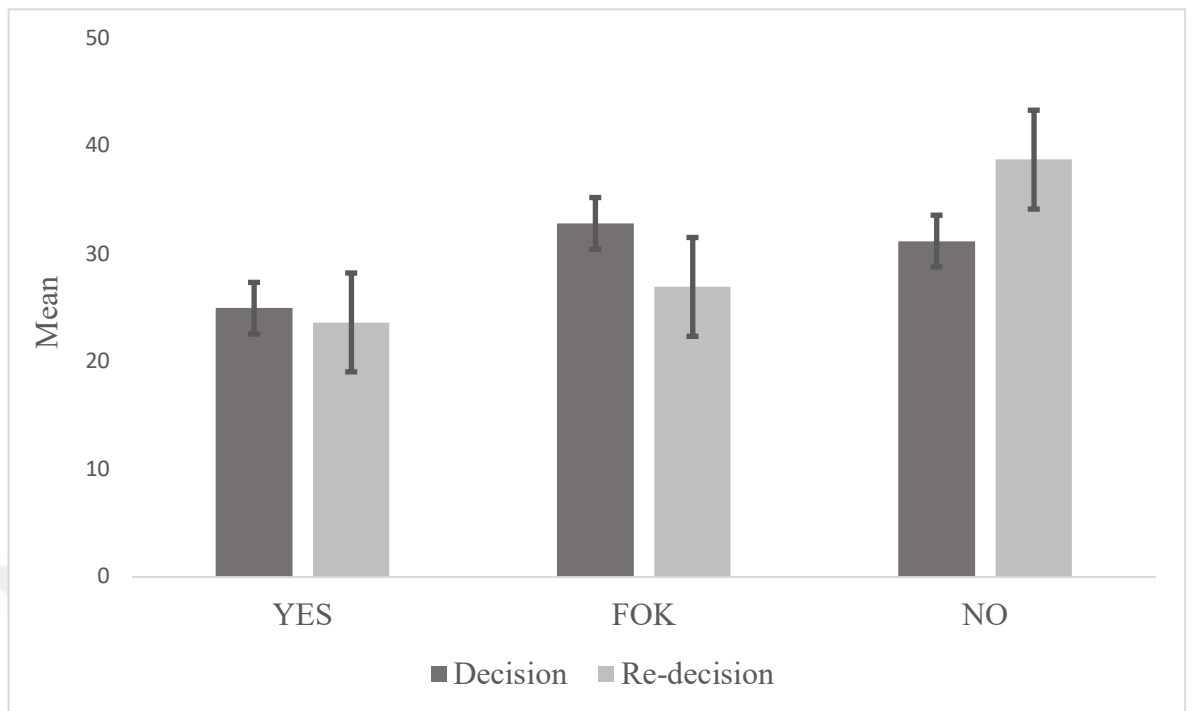


Figure 2. Mean Values for “Yes”, “FOK”, “No” Responses in Decision and Re-decision Phases

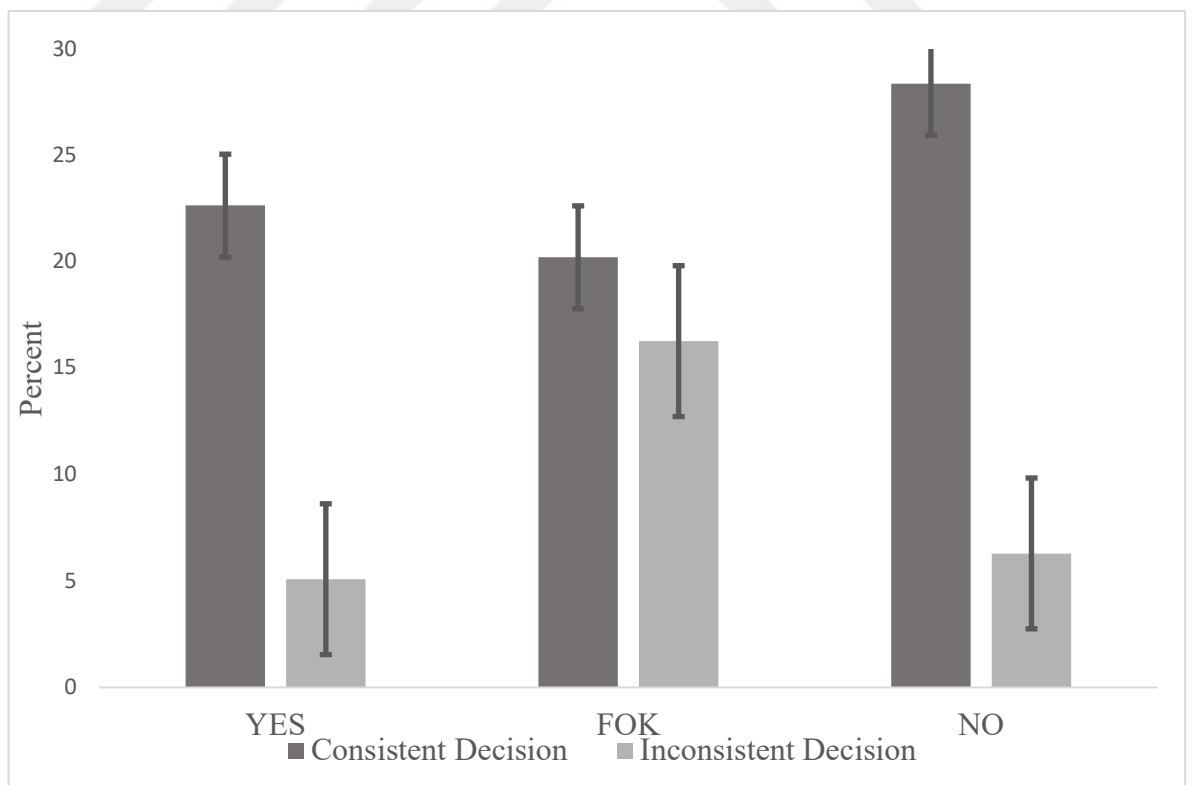


Figure 3. Percent Values for Consistent and Inconsistent Responses in “Yes”, “FOK”, “No” Responses

Table 2

Paired Sample t-test for “Yes”, “FOK”, “No” Responses in Decision and Re-decision Phases

	t	df	p
YES	2.66	69	0.10
FOK	6.19	69	0.001
NO	-6.10	69	0.001

Table 3

Means and Standard Deviation Values for All Response Reaction Times in the Decision/Re-decision Phase and Reaction Times of Consistent/Inconsistent Responses

	YES		FOK		NO	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Decision Phase (ms)	910.88	161.95	976.51	208.36	1068.09	220.48
Re-decision Phase (ms)	883.17	204.83	933.40	216.41	998.21	211.57
Consistent Responses (ms)	862.56	164.30	910.24	212.92	984.12	246.28
Inconsistent Responses (ms)	1530.94	815.64	1818.16	635.32	1261.75	586.58

Table 4

Paired Sample t-test for Consistent/ Inconsistent “Yes”, “FOK”, “No” Responses Reaction Times in Re-decision Phase

	t	df	p
YES	-6.54	60	0.001
FOK	-12.53	69	0.001
NO	-4.12	66	0.001

3.2 ERP Results

3.2.1 Visual analyses. Within the scope of the present study, the analysis of event-related potential (ERP) grand averages was conducted separately for the “Yes”, “FOK”, and “No” responses during both the decision and re-decision phases. This analysis aimed to identify specific peaks of interest and corresponding amplitude values reported in Method section.

Despite the acquisition of data from 64 channels, this analysis focused specifically on nine specific electrode locations, comprising three midline electrodes (Fz, Cz, Pz) and six lateral electrodes (F1, F2, C1, C2, P1, P2). However, grand average topography for “Yes”, “FOK” and “No” responses were shown in Figure 4, 5 and 6, respectively. In addition, Figure 7, 8 and 9, respectively presents the ERP grand average topography of nine electrodes for “Yes”, “FOK”, and “No” responses.

Following the rejection of artifacts, the average number of usable trials for different conditions exhibited comparability for “Yes” ($M = 23.60$, $SD = 15.95$; $M = 21.57$, $SD = 15.42$), “FOK” ($M = 30.68$, $SD = 10.55$; $M = 24.94$, $SD = 12.57$) and “No” ($M = 29.40$, $SD = 15.82$; $M = 36.89$, $SD = 19.43$) at decision and re-decision phase respectively.

When examining the regional comparisons for “Yes” responses, it can be observed that the amplitude of the N100 component during the decision and re-decision phases is higher at the Cz and Pz electrodes than the Fz electrode. Furthermore, the amplitude of the N100 component during the re-decision phase is higher than the decision phase (at the Fz and Cz electrodes). During the decision phase, the amplitude of the P200 component decreases from Fz to Pz, while during the re-decision phase, the amplitude at the Cz electrode appears to be greater than Fz electrode. In the Fz electrode, the amplitude during the re-decision phase is lower than that during the decision phase, whereas in the Cz electrode, the opposite pattern is observed. In the middle time window (250-500 ms), it can be said that the amplitude at Fz is higher than at Cz electrodes. Looking at the Fz electrode, the amplitude value in the re-decision phase seems to have a higher amplitude than the amplitude value in the decision phase. In the Cz electrode, the results were different. The differentiation between the decision and re-decision phases in the 400-650 ms and 651-900 ms time windows increases from frontal to parietal regions, with the re-decision phase having a higher amplitude.

The visual regional comparison analyses conducted for "FOK" responses indicate that the amplitude of the N100 component at the Pz and Cz electrodes is higher than Fz electrode during both the decision and re-decision phases. It can be stated that the amplitude of the N100 component observed at the Fz and Cz electrodes during the re-decision phase is higher than that during the decision phase. The amplitude of the P200 component decreases from frontal to parietal areas, and higher amplitude P200 component is observed during the decision phase compared to the re-decision phase. In the middle time window (250-500 ms), it can be said that the amplitude at Fz is higher than at Cz electrodes. The amplitude value in the re-decision phase is higher at the Fz electrode than the amplitude in the decision phase. However, ERP wave forms were quite similar at Cz electrode. In the decision and re-decision phases, the differentiation in the later time window (400-650 ms and 651-900 ms) increases from frontal to parietal areas. The re-decision phase exhibits higher amplitude.

The visual regional comparisons for "No" responses indicate that the amplitude of the N100 component is higher at the Fz and Pz electrodes during the decision phase, and at the Cz and Fz electrodes during the re-decision phase. It can be stated that the amplitude of the N100 component observed at the Fz and Cz electrodes during the re-decision phase is higher than that during the decision phase. However, this pattern is reversed at the Pz electrode. The amplitude of the P200 component decreases from frontal to parietal areas, and higher amplitude P200 component is observed during the decision phase compared to the re-decision phase. In the middle time window (250-500 ms), the amplitude at Fz is higher than at Cz electrodes. While ERP wave forms were quite similar at Cz electrode between the decision-re-decision phases, the amplitude in the re-decision phase for the Fz electrode is higher than the amplitude in the decision phase. In the later time window, the differentiation between the decision and re-decision phases increases from frontal to parietal electrodes. The re-decision phase exhibits higher amplitude.

Furthermore, when examining the within-hemispheric comparison of "Yes" responses visually, no differences are observed in the N100 and P200 components as we move from right to left across frontal, central, and parietal electrodes. In the middle time window (250-500 ms), it can be said that the amplitude at Fz and F2 electrodes is higher than F1 electrode. Also, visual analyses show that the amplitude at Cz and C2 electrodes is higher than C1 electrode. When looking at the later time windows

(400-650 ms, 651-900 ms), the amplitude at Pz and P2 electrodes is greater than P1 electrode.

In the "FOK" responses, the N100 amplitude appears to have higher amplitude at the Cz and Cz electrodes compared to the C1 electrode. There is no visual intra-hemispheric difference in frontal and parietal electrodes. The P200 component does not differentiate hemispherically at the frontal, central, and parietal electrodes. However, when the 250-500 ms middle time window and the late time window (400-650ms, 651-900 ms) are examined, it is observed that the average amplitude at the Fz and F2 electrodes is higher than F1 electrode. Furthermore, visual analyses show that the amplitude at Cz and C2 electrodes is higher than C1 electrode.

Finally, looking at the hemispheric comparison of the "No" responses, it is observed that the amplitude at the re-decision phase is higher at the frontal electrodes for the N100 component compared to the decision phase, while this pattern is the opposite for the parietal electrodes. When the P200 component is examined, an difference is observed only in the frontal electrodes. Visually, the amplitude of P200 at the Fz and F2 electrodes is higher than F1. When examining the middle time window (250-500 ms), the within-hemispheric comparison of the frontal and central electrodes does not reveal any visually differences. In the late time window of 400-651 ms, especially in the parietal electrodes, the re-decision phase seems to have higher amplitude than the decision phase. Lastly, the Pz and P2 electrodes have higher amplitude than the P1 electrode in the late time window of 651-900 ms.

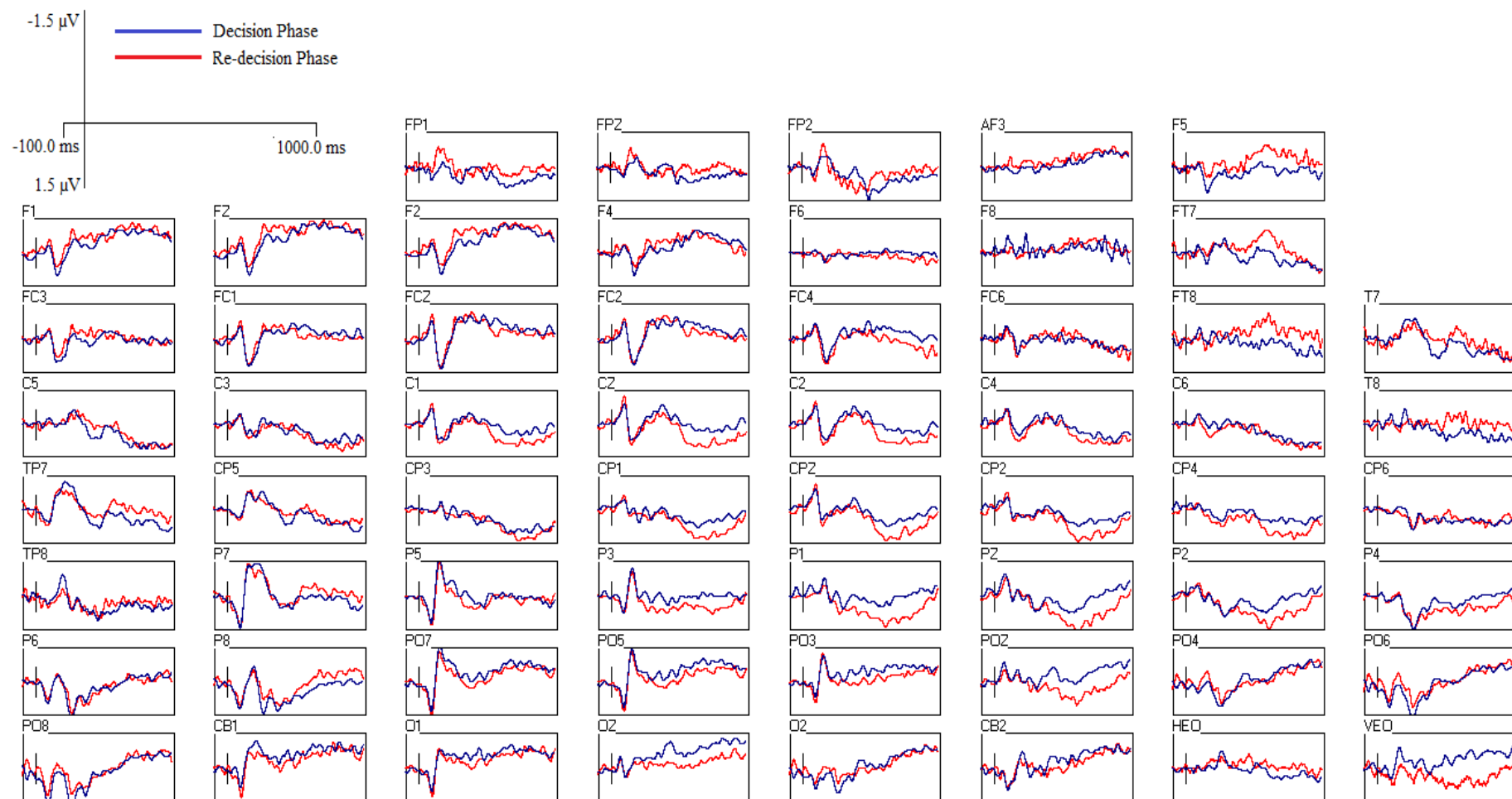


Figure 4. Grand average topography during "Yes" responses at the decision and re-decision phases.

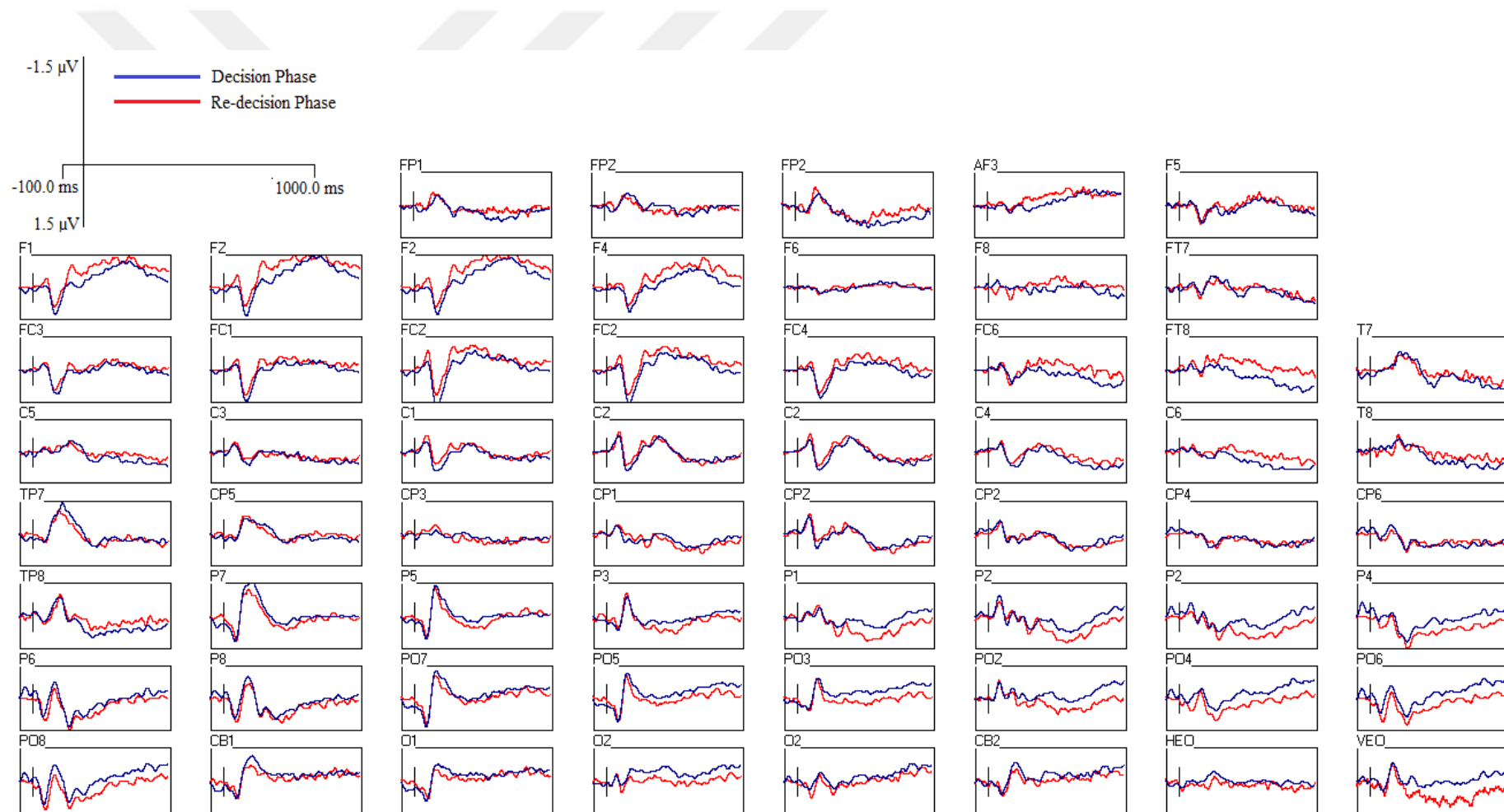


Figure 5. Grand average topography during "FOK" responses at the decision and re-decision phases.

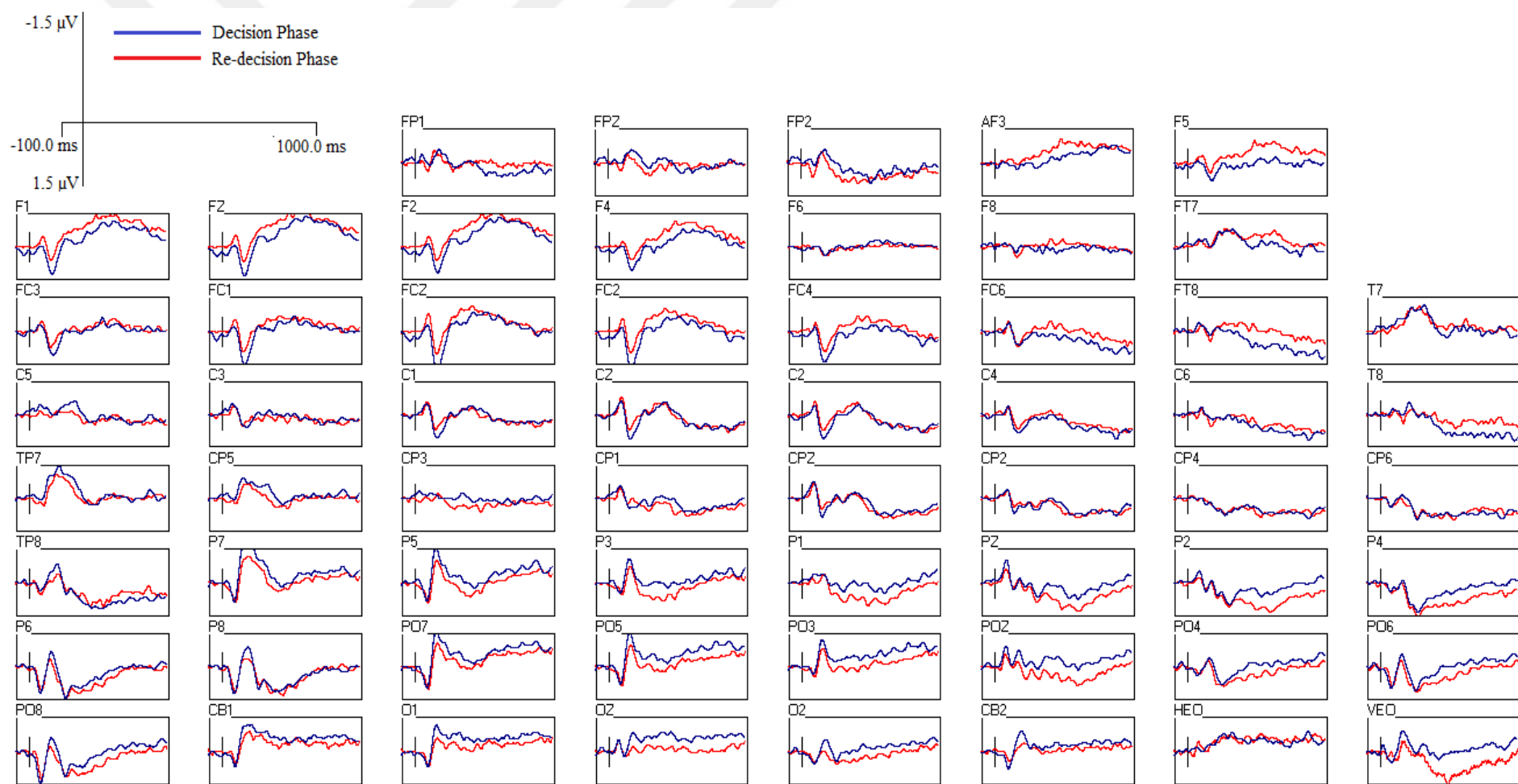


Figure 6. Grand average topography during "No" responses at the decision and re-decision phases.

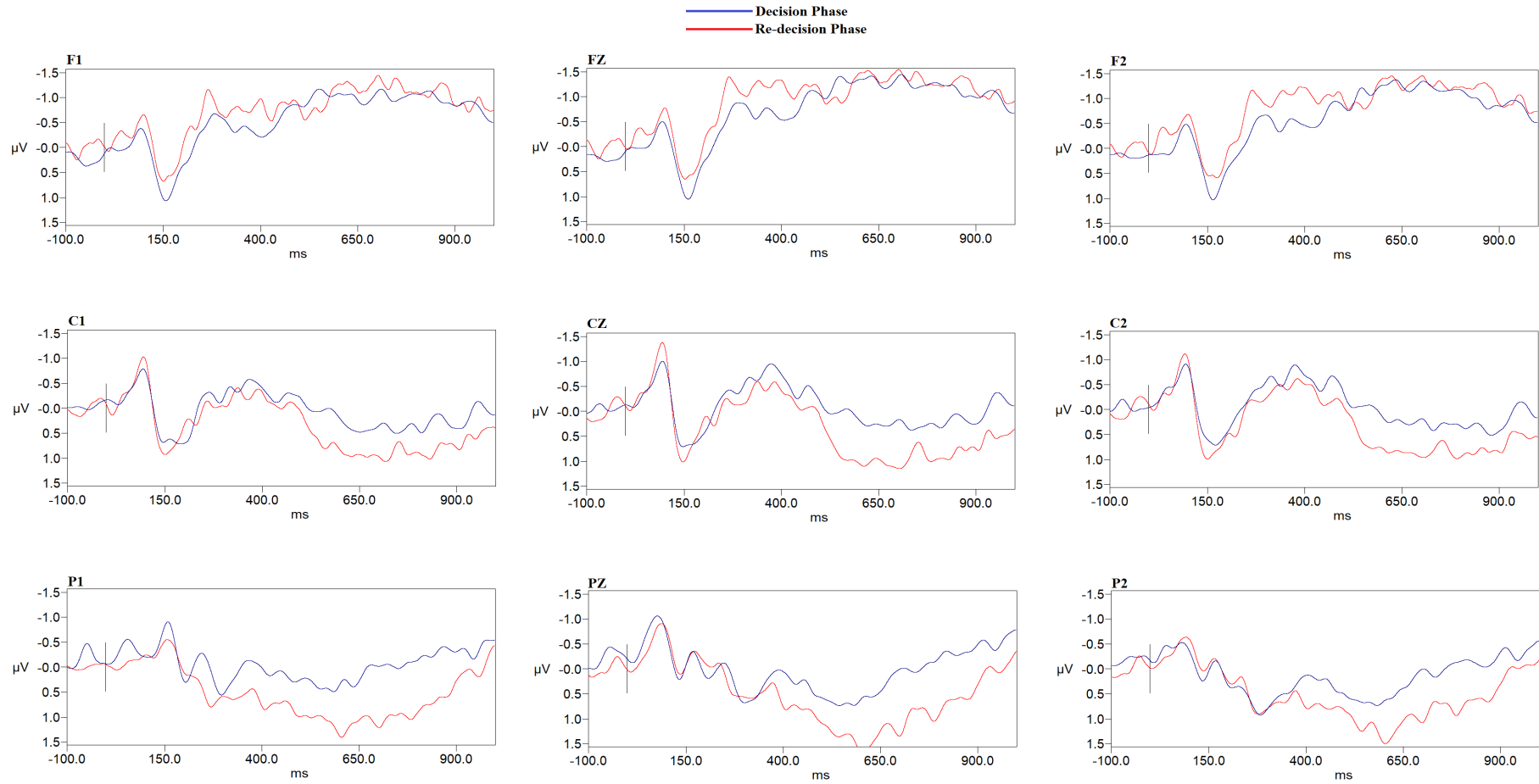


Figure 7. Grand average topography for 9 channels during "Yes" responses at the decision and re-decision phases.



Figure 8. Grand average topography for 9 channels during "FOK" responses at the decision and re-decision phases.

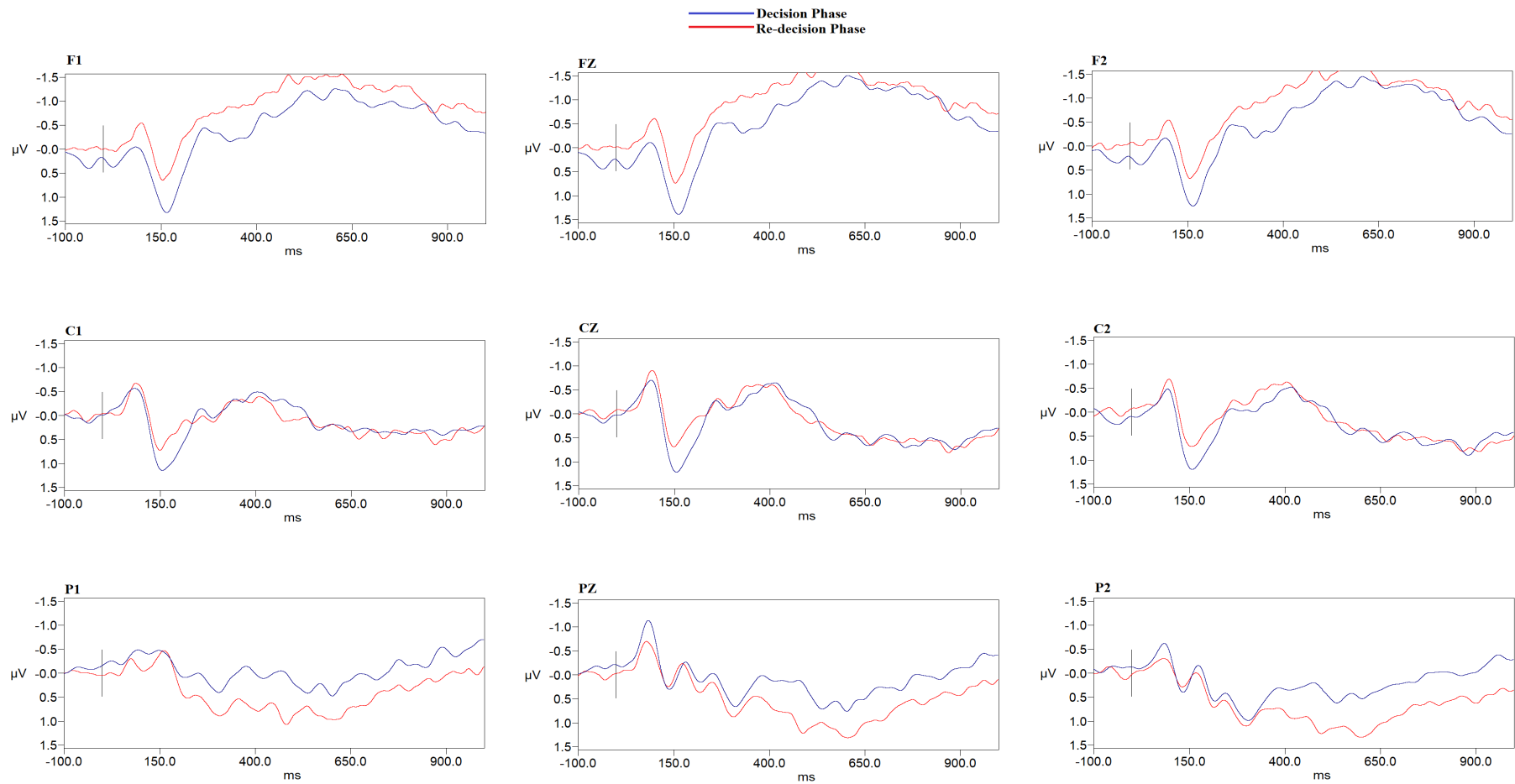


Figure 9. Grand average topography for 9 channels during "No" responses at the decision and re-decision phases.

3.2.2 Statistical results. Statistical analyses for stimulus-locked ERPs for each response at third (decision) and fourth (re-decision) phase were carried in two steps: regional and within hemispheric comparisons. Amplitudes for each response were analyzed separately. Based on the visual analyses, we analyzed amplitude of N100, P200 peaks, and also ERPs at 250-500 ms, 400-650 ms, and 651-900 ms time windows. First, the analyses were conducted using with 2 (decision phase: decision, re-decision) x 3 (channel location: Fz, Cz, Pz) repeated measure ANOVA for each response separately. Second, analyses were carried out via repeated measure ANOVA for each response separately as 2 (decision phase: decision, re-decision) x 3 (channel location: left, middle, right). Furthermore, amplitudes for each response in the two phases were analyzed separately for two early components (N100, P200) and middle time window (250-500 ms) and two late time windows (400-650 ms and 651-900 ms). As a post-hoc comparison procedure, the Bonferroni analysis was conducted for multiple comparisons. In cases where the assumption of sphericity was violated, Greenhouse-Geisser was selected to report the results. All statistically significant results were detailed and reported.

3.2.2.1 Regional comparisons for ERP amplitudes of “Yes”, “FOK” and “No” responses at decision and re-decision phase.

3.2.2.1.1 N100 component.

3.2.2.1.1.1 Comparison decision and re-decision for “Yes” responses. The analysis results for “Yes” responses have shown that there is no significant main effect or interaction effect between the decision phase and channel locations ($p > .05$) (see Appendix 1).

3.2.2.1.1.2 Comparison decision and re-decision for “FOK” responses. The analysis results for “FOK” responses have indicated that there is a significant main effect effect of channel location ($F(2, 74) = 3.35, p < .05, \eta^2 = .08$). The N100 amplitude values at Pz ($M = -2.14, SE = 0.20$) and Cz ($M = -2.11, SE = 0.22$) electrodes higher than Fz electrode ($M = -1.69, SE = 0.13$). There is a marginal significant interaction effect between decision phases and channel locations ($F = .795$

$F(2, 74) = 3.04, p = .054, \eta^2 = .07$). According to the post-hoc analysis, during the decision phase, the N100 component at Pz ($M = -2.31, SE = 0.22$) and Cz ($M = -1.84, SE = 0.19$) electrodes has higher amplitude than the Fz ($M = -1.53, SE = 0.15$) electrode. When looking at the re-decision phase, the N100 component at Cz ($M = -2.37, SE = 0.33$) and Pz ($M = -1.97, SE = 0.24$) electrodes produced higher amplitude compared to the Fz ($M = -1.86, SE = 0.23$) electrode. Additionally, during the re-decision phase, the N100 component at Fz ($M = -1.86, SE = 0.23$) and Cz ($M = -2.37, SE = 0.33$) electrodes has higher amplitude than the Fz ($M = -1.53, SE = 0.15$) and Cz ($M = -1.84, SE = 0.19$) electrodes during the decision phase. However, in the case of the Pz electrode, the opposite pattern is observed at decision ($M = -2.31, SE = 0.22$) and re-decision ($M = -1.97, SE = 0.24$) phases.

3.2.2.1.1.3 Comparison decision and re-decision for “No” responses. The analysis results for “No” responses have shown that there is no significant main effect ($p > .05$). However, there is a significant interaction effect between decision phases and channel locations ($\Lambda = .812 F(2, 78) = 5.77, p < .05, \eta^2 = .12$). According to the post-hoc analysis, during the decision phase, the N100 component at Pz ($M = -2.10, SE = 0.24$) and Cz ($M = -1.82, SE = 0.17$) electrodes has higher amplitude compared to the Fz ($M = -1.35, SE = 0.16$) electrode. When looking at the re-decision phase, the N100 component at Cz ($M = -2.04, SE = 0.22$) and Fz ($M = -1.85, SE = 0.19$) electrodes shows higher amplitude compared to the Pz ($M = -1.62, SE = 0.18$) electrode. Also, during the re-decision phase, the N100 component at Fz ($M = -1.85, SE = 0.19$) and Cz ($M = -2.04, SE = 0.22$) electrodes has higher amplitude compared to the Fz ($M = -1.35, SE = 0.16$) and Cz ($M = -1.82, SE = 0.17$) electrodes during the decision phase. But, in the case of the Pz electrode, the opposite pattern is observed at decision ($M = -2.10, SE = 0.24$) and re-decision ($M = -1.62, SE = 0.18$) phases.

3.2.2.1.2 P200 component.

3.2.2.1.2.1 Comparison decision and re-decision for “Yes” Responses. The analysis results for “Yes” responses have shown that there is no significant main effect or interaction effect between the decision phase and channel locations ($p > .05$) (see Appendix 1).

3.2.2.1.2.2 *Comparison decision and re-decision for “FOK” Responses.* The analysis results for “FOK” responses have indicated that there is a significant main effect of decision type ($A = .860 F (1, 29) = 4.70, p < .05, \eta^2 = .14$). The P200 amplitude values at decision phase ($M = 2.35, SE = 0.18$) is higher compared to the re-decision phase ($M = 1.89, SE = 0.18$). Besides, there is a marginal significant main effect of channel location ($A = .759 F (1.56, 45.48) = 3.23, p = .060, \eta^2 = .10$). The P200 amplitude values at Cz ($M = 2.32, SE = 0.18$) and Fz ($M = 2.23, SE = 0.20$) electrodes are higher compared to the Pz electrode ($M = 1.82, SE = 0.18$).

3.2.2.1.2.3 *Comparison decision and re-decision for “No” Responses.* The analysis results for “No” responses have indicated that there is a significant main effect and interaction effect between the decision phase and channel locations ($p < .05$). The results indicate a main effect of channel location ($A = .755 F (1.51, 45.51) = 7.57, p < .05, \eta^2 = .20$). The P200 amplitude values at Fz ($M = 2.39, SE = 0.21$) and Cz ($M = 2.37, SE = 0.22$) electrodes are higher compared to the Pz electrode ($M = 1.56, SE = 0.19$). There is a significant interaction effect between decision phases and channel locations ($A = .818 F (2, 60) = 3.25, p < .05, \eta^2 = .09$). According to the post-hoc analysis, during the decision phase, the P200 component at Cz ($M = 2.59, SE = 0.30$) and Fz ($M = 2.59, SE = 0.31$) electrodes has higher amplitude compared to the Pz ($M = 1.45, SE = 0.22$) electrode. When looking at the re-decision phase, the P200 component at Fz ($M = 2.20, SE = 0.20$) and Cz ($M = 2.15, SE = 0.22$) electrodes shows higher amplitude compared to the Pz ($M = 1.68, SE = 0.22$) electrode. Furthermore, during the decision phase, the P200 component at Fz ($M = 2.59, SE = 0.31$) and Cz ($M = 2.59, SE = 0.30$) electrodes has higher amplitude compared to the Fz ($M = 2.20, SE = 0.20$) and Cz ($M = 2.15, SE = 0.22$) electrodes during the re-decision phase. However, in the case of the Pz electrode, the opposite pattern is observed at decision ($M = 1.45, SE = 0.22$) and re-decision ($M = 1.68, SE = 0.22$) phases. There was no other significant main and interaction effect ($p > .05$) (see Appendix 3).

3.2.2.1.3 *250-500 ms time windows.* The regional analyses conducted separately for “Yes”, “FOK”, and “No” responses were performed only for the frontal and central region for 250-500 ms time window.

3.2.2.1.3.1 *Comparison decision and re-decision for “Yes” Responses.* The analysis results for “Yes” responses have indicated that there is a significant main effect of channel location ($\lambda = .858$ $F(1, 69) = 11.38, p < .05, \eta^2 = .14$). According to the post-hoc analysis, the mean amplitude values at Fz ($M = -1.10, SE = 0.24$) electrode is higher than Cz electrode ($M = -0.33, SE = 0.22$). There was no other significant main and interaction effect ($p > .05$) (see Appendix 1).

3.2.2.1.3.2 *Comparison decision and re-decision for “FOK” Responses.* The analysis results for “FOK” responses have indicated that there is a significant main effect of channel location ($\lambda = .929$ $F(1, 69) = 5.27, p < .05, \eta^2 = .07$). According to the post-hoc analysis, the mean amplitude values at Fz ($M = -0.96, SE = 0.23$) electrode is higher than Cz electrode ($M = -0.46, SE = 0.23$). There was no other significant main and interaction effect ($p > .05$) (see Appendix 2).

3.2.2.1.3.3 *Comparison decision and re-decision for “No” Responses.* The analysis results for “No” responses have indicated that there is a significant main effect of channel location ($\lambda = .831$ $F(1, 68) = 13.85, p < .05, \eta^2 = .16$). According to the post-hoc analysis, the mean amplitude values at Fz ($M = -1.09, SE = 0.23$) electrode is higher compared to the Cz electrode ($M = -0.37, SE = 0.23$). There was no other significant main and interaction effect ($p > .05$) (see Appendix 3).

3.2.2.1.3 400-650 ms time windows.

3.2.2.1.3.1 *Comparison decision and re-decision for “Yes” Responses.* The analysis results of the “Yes” responses, which indicate the presence of an channel location main effect ($\lambda = .639, F(1.38, 95.69) = 21.48, p < .05, \eta^2 = .23$), show that the mean amplitude values at Fz ($M = -1.30, SE = 0.27$) and Pz ($M = 0.92, SE = 0.21$) electrodes are higher compared to the Cz electrode ($M = 0.18, SE = 0.23$).

3.2.2.1.3.2 *Comparison decision and re-decision for “FOK” Responses.* The analysis results of the “FOK” responses, which indicate the presence of an channel location main effect ($\lambda = .615, F(1.63, 112.70) = 29.93, p < .05, \eta^2 = .30$), show that the mean amplitude values at Fz ($M = -1.40, SE = 0.21$) and Pz ($M = 0.78, SE = 0.21$) electrodes are higher compared to the Cz electrode ($M = 0.008, SE = 0.22$).

3.2.2.1.3.3 *Comparison decision and re-decision for “No” Responses.* The analysis results of the “No” responses, which indicate the presence of an channel location main effect ($\lambda = .565$, $F(1.49, 102.90) = 33.39$, $p < .05$, $\eta^2 = .32$), show that the mean amplitude values at Fz ($M = -1.57$, $SE = 0.23$) and Pz ($M = 0.81$, $SE = 0.21$) electrodes are higher compared to the Cz electrode ($M = 0.03$, $SE = 0.22$).

3.2.2.1.4 *651-900 ms time windows.*

3.2.2.1.4.1 *Comparison decision and re-decision for “Yes” Responses.* The analysis results of the “Yes” responses, which indicate the presence of a marginal significant decision type main effect ($\lambda = .949$, $F(1, 69) = 3.72$, $p = .058$, $\eta^2 = .05$) and significant channel location main effect ($\lambda = .497$, $F(1.55, 107.55) = 26.92$, $p < .05$, $\eta^2 = .28$). For channel location main effect post-hoc results show that the mean amplitude values at Fz ($M = -1.43$, $SE = 0.24$) and Cz ($M = 0.53$, $SE = 0.20$) electrodes are higher compared to the Pz electrode ($M = 0.44$, $SE = 0.19$). And for decision marginal main effect post-hoc results indicate that the mean amplitude value of the decision phase ($M = -0.37$, $SE = 0.16$) is higher than that of the re-decision phase ($M = 0.06$, $SE = 0.18$).

3.2.2.1.4.2 *Comparison decision and re-decision for “FOK” Responses.* The analysis results of the “FOK” responses, which indicate the presence of an channel location main effect ($\lambda = .532$, $F(1.56, 107.61) = 33.22$, $p < .05$, $\eta^2 = .32$), show that the mean amplitude values at Fz ($M = -1.40$, $SE = 0.19$) and Cz ($M = 0.43$, $SE = 0.18$) electrodes are higher compared to the Pz electrode ($M = 0.35$, $SE = 0.18$).

3.2.2.1.4.3 *Comparison decision and re-decision for “No” Responses.* The analysis results of the “No” responses, which indicate the presence of an channel location main effect ($\lambda = .472$, $F(1.52, 103.94) = 38.84$, $p < .05$, $\eta^2 = .36$), show that the mean amplitude values at Fz ($M = -1.36$, $SE = 0.19$) and Cz ($M = 0.53$, $SE = 0.16$) electrodes are higher compared to the Pz electrode ($M = 0.50$, $SE = 0.17$).

3.2.2.2 Within hemispheric comparisons for ERP amplitudes of “Yes”, “FOK” and “No” responses at decision and re-decision phase.

3.2.2.2.1 N100 component.

3.2.2.2.1.1 Comparison decision and re-decision for “Yes” Responses. The results of the lateral analysis conducted for “Yes” responses in the frontal, central, and parietal regions indicate that no significant main or interaction effects were observed in any of them ($p > .05$) (see Appendix 1).

3.2.2.2.1.2 Comparison decision and re-decision for “FOK” Responses. The results of the lateral analysis conducted for “FOK” responses in the frontal, central, and parietal regions indicate that only the lateral analysis of central electrodes reveals a significant main effect of channel location ($\lambda = .822$, $F(2, 96) = 3.99$, $p < .05$, $\eta^2 = .07$). Post-hoc comparison results indicate that the N100 component in Cz ($M = -1.98$, $SE = 0.16$) and C2 ($M = -1.83$, $SE = 0.14$) channels has higher amplitude compared to the C1 ($M = -1.75$, $SE = 0.13$) electrode. There was no other significant main and interaction effect ($p > .05$) (see Appendix 2).

3.2.2.2.1.3 Comparison decision and re-decision for “No” Responses. The results of the lateral analysis conducted for “No” responses in the frontal, central, and parietal regions indicate that only the lateral analysis of frontal ($\lambda = .912$, $F(1, 43) = 4.13$, $p < .05$, $\eta^2 = .08$) and parietal ($\lambda = .727$, $F(1, 42) = 15.79$, $p < .05$, $\eta^2 = .27$) electrodes reveals a significant main effect of decision. Post-hoc comparisons conducted for the lateral analysis in the frontal region indicate that the N100 component in the re-decision phase ($M = -1.72$, $SE = 0.16$) has higher amplitude compared to the decision phase ($M = -1.39$, $SE = 0.12$). In contrast, the lateral analysis in the parietal region shows the opposite pattern. In this region, the N100 component during the decision phase ($M = -2.31$, $SE = 0.21$) has higher amplitude compared to the re-decision phase ($M = -1.70$, $SE = 0.15$). There was no other significant main and interaction effect ($p > .05$) (see Appendix 3).

3.2.2.2.2 P200 component.

3.2.2.2.2.1 *Comparison decision and re-decision for “Yes” Responses.* The analysis results indicate that there is a marginally significant channel location main effect for “Yes” ($\lambda = .845$, $F(2, 68) = 2.91$, $p = .06$, $\eta^2 = .07$) response in parietal electrodes. The post-hoc analysis results for “Yes” responses indicate that the mean amplitude value at Pz ($M = 2.76$, $SE = 0.27$) and P2 ($M = 2.62$, $SE = 0.22$) electrodes is significantly higher compared to the P1 ($M = 2.34$, $SE = 0.26$) electrode.

There are no significant main effects or interaction effects observed ($p > .05$) (see Appendix 1).

3.2.2.2.2.2 *Comparison decision and re-decision for “FOK” Responses.* The results of the lateral analysis conducted for “FOK” responses in the frontal, central and parietal regions show that no significant main or interaction effects were observed in any of them ($p > .05$) (see Appendix 2).

3.2.2.2.2.3 *Comparison decision and re-decision for “No” Responses.* The analysis results indicate that there is a marginally significant channel location main effect for “No” ($\lambda = .791$, $F(1.65, 74.27) = 3.22$, $p = .055$, $\eta^2 = .06$) response in frontal electrodes. The post-hoc analysis results for “No” responses indicate that the mean amplitude value at Fz ($M = 2.55$, $SE = 0.22$) and F2 ($M = 2.41$, $SE = 0.20$) electrodes is significantly higher compared to the F1 ($M = 2.38$, $SE = 0.21$) electrode.

There are no significant main effects or interaction effects observed ($p > .05$) (see Appendix 3).

3.2.2.2.3 *250-500 ms time windows.* The lateral analyses conducted separately for “Yes”, “FOK”, and “No” responses were performed only for the frontal and central region.

3.2.2.3.1 *Comparison decision and re-decision for “Yes” Responses.* The analysis results indicate that there is a significant channel location main effect for “Yes” ($\lambda = .749$, $F(1.49, 102.89) = 4.82$, $p < .05$, $\eta^2 = .06$) response in frontal electrodes. The post-hoc analysis results for “Yes” responses indicate that the mean amplitude value at Fz ($M = -1.10$, $SE = 0.24$) and F2 ($M = -0.90$, $SE = 0.23$) electrodes is significantly higher compared to the F1 ($M = -0.80$, $SE = 0.22$) electrode.

Also, there is a marginally significant channel location main effect for “Yes” ($\lambda = .931$, $F(1.62, 111.89) = 3.21$, $p = .054$, $\eta^2 = .04$) response in central electrodes. The post-hoc analysis results for “Yes” responses indicate that the mean amplitude value at C2 ($M = -0.40$, $SE = 0.23$) and Cz ($M = -0.33$, $SE = 0.22$) electrodes is significantly higher compared to the C1 ($M = -0.14$, $SE = 0.21$) electrode.

3.2.2.3.2 Comparison decision and re-decision for “FOK” Responses. The analysis results indicate that there is a significant channel location main effect for “FOK” ($\lambda = .833$, $F(1.58, 109.37) = 4.37$, $p < .05$, $\eta^2 = .06$) response in frontal electrodes. For “FOK” responses, it can be observed that the mean amplitude value at Fz ($M = -0.96$, $SE = 0.23$) and F2 ($M = -0.90$, $SE = 0.21$) electrodes is significantly higher than the F1 ($M = -0.72$, $SE = 0.20$) electrode.

Also, there is a significant channel location main effect for “FOK” ($\lambda = .890$, $F(2, 138) = 3.21$, $p < .05$, $\eta^2 = .06$) response in central electrodes. The post-hoc analysis results for “FOK” responses indicate that the mean amplitude value at C2 ($M = -0.48$, $SE = 0.21$) and Cz ($M = -0.46$, $SE = 0.23$) electrodes is significantly higher compared to the C1 ($M = -0.23$, $SE = 0.20$) electrode.

3.2.2.3.3 Comparison decision and re-decision for “No” Responses. There are no significant main effects or interaction effects observed both of frontal and central electrodes ($p > .05$) (see Appendix 3).

3.2.2.2.4 400-650 ms time windows.

3.2.2.2.4.1 Comparison decision and re-decision for “Yes” Responses. The lateral analysis results for “Yes” responses in the frontal, central, and parietal regions indicate that there is a main effect of decision type in the central region ($\lambda = .945$, $F(1, 69) = 4.01$, $p < .05$, $\eta^2 = .05$) and a main effect of channel location in the parietal region ($\lambda = .885$, $F(1.40, 96.96) = 6.77$, $p < .05$, $\eta^2 = .08$).

Post-hoc analyses conducted for the main effect of decision type in the central region reveal that the mean amplitude value in the re-decision phase ($M = 0.44$, $SE = 0.27$) is significantly higher compared to the decision phase ($M = 0.06$, $SE = 0.23$). Post-hoc analyses conducted for the main effect of channel location in the parietal

region indicate that the mean amplitude value at P2 ($M = 0.95$, $SE = 0.19$) and Pz ($M = 0.92$, $SE = 0.21$) electrodes is significantly higher compared to the P1 electrode ($M = 0.39$, $SE = 0.16$).

In addition, there is a marginally significant main effect of channel location in the frontal region ($\Lambda = .789$, $F(1.38, 95.64) = 3.11$, $p = .06$, $\eta^2 = .04$). The post-hoc analysis results indicate that the mean amplitude value of Fz ($M = -1.30$, $SE = 0.27$) and F2 ($M = -1.15$, $SE = 0.26$) electrodes is significantly higher compared to the F1 electrode ($M = -1.04$, $SE = 0.25$).

3.2.2.2.4.2 Comparison decision and re-decision for “FOK” Responses. The lateral analysis results for “FOK” responses in the frontal, central, and parietal regions indicate that there is a main effect of channel location in the frontal region ($\Lambda = .845$, $F(1.53, 106.17) = 4.93$, $p < .05$, $\eta^2 = .06$). The post-hoc analysis results indicate that the mean amplitude value of Fz ($M = -1.40$, $SE = 0.21$) and F2 ($M = -1.38$, $SE = 0.21$) electrodes is significantly higher compared to the F1 electrode ($M = -1.16$, $SE = 0.19$).

3.2.2.2.4.3 Comparison decision and re-decision for “No” Responses. The lateral analysis results for “No” responses in the frontal, central, and parietal regions indicate that there is a marginally significant main effect of decision type in the parietal region ($\Lambda = .947$, $F(1, 69) = 3.84$, $p = .054$, $\eta^2 = .05$). The post-hoc analysis results of parietal region, indicate that the mean amplitude value in re-decision phase ($M = 0.98$, $SE = 0.22$) is significantly higher compared to decision phase ($M = 0.51$, $SE = 0.20$).

There are no other significant main effects or interaction effects observed ($p > .05$) (see Appendix 3).

3.2.2.2.5 651-900 ms time windows.

3.2.2.2.5.1 Comparison decision and re-decision for “Yes” Responses. The lateral analysis results for “Yes” responses in the frontal, central, and parietal regions indicate that there is a main effect of decision type in the parietal region ($\Lambda = .944$, $F(1, 69) = 4.09$, $p < .05$, $\eta^2 = .05$). The post-hoc analysis results of parietal region, indicate that the mean amplitude value in re-decision phase ($M = 0.68$, $SE = 0.21$) is significantly higher compared to decision phase ($M = 0.15$, $SE = 0.22$).

3.2.2.2.5.2 Comparison decision and re-decision for “FOK” Responses. The lateral analysis results for “FOK” responses in the frontal, central, and parietal regions indicate that there is a main effect of channel location in the frontal region ($\Lambda = .872$,

$F(1.60, 110.68) = 4.27, p < .05, \eta^2 = .05$). The post-hoc analysis results indicate that the mean amplitude value of Fz ($M = -1.40, SE = 0.19$) and F2 ($M = -1.39, SE = 0.19$) electrodes is significantly higher compared to the F1 electrode ($M = -1.17, SE = 0.16$).

3.2.2.2.5.3 Comparison decision and re-decision for "No" Responses. The lateral analysis results for "No" responses in the frontal, central, and parietal regions indicate that there is a marginally significant main effect of channel location in the parietal region ($\Lambda = .891, F(1.64, 111.84) = 3.26, p = .051, \eta^2 = .04$). The post-hoc analysis results indicate that the mean amplitude value of Pz ($M = 0.50, SE = 0.17$) and P2 ($M = 0.49, SE = 0.14$) electrodes is significantly higher compared to the P1 electrode ($M = 0.26, SE = 0.16$).

There are no other significant main effects or interaction effects observed ($p > .05$) (see Appendix 3).

3.3 Summary of ERP Results

The statistical analyses for stimulus-locked ERPs were conducted in two steps: regional and hemispheric comparisons. The amplitudes for each response in the decision and re-decision phases were separately analyzed, focusing on two early components, one early time window and two late time windows. Considering regional comparisons, it can be observed that "Yes" responses exhibited main effects of channel location only in the 250-500 ms, 400-650 ms and 651-900 ms time windows, and a main effect of decision type in the 651-900 ms time window. When examining the "FOK" responses, it can be observed that the N100 component shows a main effect of channel location and a marginally significant interaction effect. In the P200 component, there is a significant main effect of decision type. Furthermore, in the 250-500 ms, 400-650 ms and 651-900 ms time windows, there is a main effect of channel location. The "No" responses, on the other hand, demonstrate an interaction effect of channel location and decision type in both the N100 and P200 components. Additionally, it shows a main effect of channel location in the P200 component, 250-500 ms, 400-650 ms and 651-900 ms time windows. All significant findings of the regional comparisons were summarized in "Table 5" which presents an ANOVA table.

In the second analysis section, we focused on within-hemispheric comparisons, and results indicated that no significant main or interaction effect was observed for "Yes" responses for the N100 and P200 components. On the contrary, for ERPs at the 250-500 ms time window, there is a main effect of channel location for frontal and central electrodes, while in the 400-650 ms time window, there is a main effect of decision type for central electrodes and a main effect of channel location for parietal electrodes. For the ERPs at the 651-900 ms time window, only a decision type main effect was observed for parietal electrodes. "FOK" responses show a main effect of channel location for central electrodes in the N100 component. In the 250-500 ms, there is a main effect of channel location for frontal and central electrodes. In the 400-650 ms, and 651-900 ms time windows, "FOK" responses exhibit a main effect of channel location for frontal electrodes. Finally, when examining the within-hemispheric comparisons of "No" responses, considering the N100 component, a significant main effect of decision type is observed for both frontal and parietal electrodes. No significant findings are reported for the P200 component and the 250-500 ms time window. However, focusing on the later time windows, it is found that in the 400-650 ms time window, "No" responses exhibit a decision type main effect for parietal electrodes, and in the 651-900 ms time window, they demonstrate a channel location main effect for parietal electrodes. All significant findings of the within-hemispheric comparisons were summarized in "Table 6" which also presents an ANOVA table.

Table 5

Regional Comparisons ERP amplitudes of “Yes”, “FOK” and “No” responses at decision and re-decision phase: Analysis of Variance Summary Table with F Values

Responses	Effect	N100	P200	250- 500 ms	400-650 ms	651-900 ms
YES	<u>Decision Phase (A)</u>	0.81	0.57	0.10	3.32	3.72^a
	<u>Channel Location (B)</u>	0.89	1.89	11.38^{**}	21.48^{**}	26.92^{**}
	<u>A x B</u>	1.41	1.04	1.68	0.22	0.54
FOK	<u>Decision Phase (A)</u>	0.80	4.70[*]	1.21	0.001	0.52
	<u>Channel Location (B)</u>	3.35[*]	3.23^a	5.27[*]	29.93^{**}	33.22^{**}
	<u>A x B</u>	3.04^a	0.74	1.05	0.73	0.63
NO	<u>Decision Phase (A)</u>	0.37	0.81	0.10	0.86	2.89
	<u>Channel Location (B)</u>	1.44	7.57^{**}	13.85^{**}	33.39^{**}	38.84^{**}
	<u>A x B</u>	5.77^{**}	3.25[*]	1.08	0.98	0.29

^{**}, $p < 0.01$; ^{*}, $p < 0.05$; ^a, marginally significant

Table 6

Within Hemispheric Comparisons ERP amplitudes of “Yes”, “FOK” and “No” responses at decision and re-decision phase: Analysis of Variance Summary Table

Responses	Effect	Channel Locations	N100	P200	250-500 ms	400-650 ms	651-900 ms
YES	Decision Phase (A)	Frontal	1.97	0.03	0.22	0.60	0.44
		Central	0	1.71	0.81	4.01*	2.66
		Parietal	1.35	0.03		0.36	4.09*
	Channel Location (B)	Frontal	0.97	0.96	4.82*	3.11^a	2.01
		Central	1.80	0.42	3.21^a	0.46	0.25
		Parietal	0.70	2.91^a		6.77**	0.15
	A x B	Frontal	0.03	0.33	1.09	0.65	0.94
		Central	1.02	0.49	0.17	0.95	0.25
		Parietal	2.06	0.02		2.41	0.66
	Decision Phase (A)	Frontal	2.20	0.92	1.52	0.27	0.002
		Central	1.36	2.09	0.61	0.39	0.21
		Parietal	1.21	1.09		2.17	3.15
FOK	Channel Location (B)	Frontal	1.89	0.75	4.37*	4.93*	4.27*
		Central	3.99*	2.73	4.18*	1.22	1.71
		Parietal	1.38	2.43		0.71	2.07
	A x B	Frontal	0.03	0.87	0.70	0.52	0.12
		Central	1.51	1.74	0.34	0.12	0.61
		Parietal	1.04	0.92		1.81	0.65
	Decision Phase (A)	Frontal	4.13*	1.36	0.88	0.26	0.35
		Central	0.06	1.52	0.17	0.12	0.37
		Parietal	15.79**	1.25		3.84^a	2.93
	Channel Location (B)	Frontal	1.68	3.22^a	2.52	2.05	1.08
		Central	2.15	0.05	1.33	0.26	2.74
		Parietal	0.31	2.37		1.92	3.26^a
NO	A x B	Frontal	1.76	0.87	0.37	0.64	2.09
		Central	0.93	0.25	2.14	0.45	0.15
		Parietal	0.34	2.26		0.53	0.52

******, $p < 0.01$; *****, $p < 0.05$; ^a, marginally significant

Chapter 4

Discussion

4.1 Overview

Within the scope of the current thesis study, memory-based decision making (Yes/No), and metacognitive judgments (FOK) were investigated using an episodic memory task utilizing EEG/ERP technique. As part of the study's objectives, a previously used episodic memory task was employed, which was further developed to incorporate decision and re-decision stages. With the development of this task, the current study aimed to examine the amplitude values of ERP components elicited during the decision and re-decision stages of memory-based decision making and metacognitive judgments. ERP data were obtained from nine specific electrode locations, represents frontal (Fz, F1, F2), central (Cz, C1, C2), and parietal (Pz, P1, P2) regions. During the decision and re-decision stages of "Yes," "FOK," and "No" responses, and amplitude values were analyzed. The analyses were conducted on the ERP data focusing on two early components (N100, P200) and middle time window (250-500 ms), as well as two late time windows (400-650 ms and 651-900 ms). Peak amplitude analysis was performed for the two early time components, namely N100 and P200. Additionally, mean amplitude analysis was conducted for the middle time window (250-500 ms) and two late time windows (400-650 ms and 651-900 ms). In addition to conducting regional comparisons, separate analyses were performed for Fz, Cz, and Pz electrodes to compare frontal, central, and parietal regions, considering hemispheric comparisons.

Lastly, behavioral analysis was carried out in two main steps. Firstly, percentages and mean values were calculated and compared for "Yes," "FOK," and "No" responses, as well as reaction times, during the decision and re-decision stages. Secondly, statistical comparisons were conducted by calculating the mean values and reaction times of consistent and inconsistent responses for each response type. The statistical analyses were calculated using paired sample t-tests. In this section, the

obtained behavioral and ERP findings were evaluated and discussed in light of the existing literature.

4.2 Discussion for Behavioral Results

The results showed that the percentages of "Yes," "FOK," and "No" responses in the decision phase were 27.74%, 36.50%, and 34.68%, respectively, while in the re-decision phase, they were 26.28%, 29.95%, and 43.07%. The mean comparisons of these three response types between the decision and re-decision phases were statistically significant. The mean of "Yes" and "FOK" responses was higher in the decision phase compared to the re-decision phase. On the other hand, it was observed that participants' "No" responses were higher in the re-decision phase compared to the decision phase. The episodic memory task consists of 135 stimuli randomly presented in both the decision and re-decision phases. Of these stimuli, 90 are presented during the encoding phase, while 45 are new items. Previous findings suggest that the repeated presentation of stimuli enhances recall and recognition performance (e.g. Hintzman, 1976; Poppenk & Norman, 2012). However, some studies demonstrated negative impact of repetition on source memory (e.g. Kim et al., 2012; Lee, Kim & Yi, 2020). Studies that have found the negative effect of repetition and stimulus familiarity on source memory draw attention to the cost of reducing attentional resources on repeated items (Ranganath & Rainer, 2003; Kim et al., 2012; Lee, Kim & Yi, 2020; Lange & Berry, 2021). The higher proportion of "No" responses in the re-decision phase compared to the decision phase may be attributed to the negative effect of re-presenting the stimulus set containing both old and new items on source memory.

When comparing the average RTs between the decision and re-decision stages for the three response types, it was found that there was no significant difference in the mean RTs for "Yes" responses, while a significant difference was observed for "FOK" and "No" responses. The findings indicate that the average RTs calculated for "FOK" and "No" responses are longer in the decision phase compared to the re-decision phase. Measurement of RT provides insight about the nature of the memory. In Tyler et al.'s study (1979), it was suggested that RT is associated with cognitive effort. Cognitive effort has been interpreted using RT data in many studies (Tyler et

al., 1979; Russo ve Doshier, 1983; Cooper-Martin, 1994). Human information processing capacity is limited, and effective utilization of cognitive processes such as perception, attention, and memory is required to process information, which constitutes cognitive effort (Tyler et al., 1979; Cooper-Martin, 1994). Behavioral result show that participants require more time to respond in the initial decision phase compared to the re-decision phase where they indicate that they either cannot access the memory trace for the relevant stimulus ("No" response) or currently cannot access the memory trace but will be able to recognize the relevant stimulus among the options in the future ("FOK" response). Tyler et al.'s study (1979) emphasizes that when high cognitive effort is involved, RT is longer compared to low. In the initial decision phase, participants engage in memory-based decision making and metacognitive judgments in a setup that includes both old and new items. In initial decision phase, participants differentiate between old and new items and also to remember the pair of the relevant word of old items. This demands more cognitive effort. Participants may have exerted more cognitive effort in attempting to access the relevant memory trace before providing a "FOK" or "No" response for stimuli they couldn't recall. Thus, it appears that items requiring more cognitive effort also necessitate more time for processing.

When examining the consistent and inconsistent responses between the decision and re-decision phases, the results indicate that the percentages of consistent responses for "Yes," "FOK," and "No" are 22.65%, 20.22%, and 28.38%, respectively. On the other hand, the percentages of inconsistent responses are 5.09%, 16.28%, and 6.30%, respectively. Notably that participants show a higher percentage of changing their "FOK" responses to either Yes or No responses when allowed to make a re-decision. This result shows that participants tend to engage in memory-based decision making rather than prospective metacognitive judgments during the re-decision phase for stimuli they could not recall during the decision phase but indicate they will be able to recognize among the stimuli to be presented in the future. In this study, inconsistency is considered as an uncertain situation. Compared to "Yes" and "No" responses, the uncertainty level of the "FOK" response might be higher. Because while the participant who gave the answers "Yes" and "No" made a definite judgment about whether the information about the relevant stimulus is currently in their memory or not, the situation was not the same when they answered "FOK". Uncertainty is

associated with the initiating of metacognitive processes (Fleming et al., 2012; Jia et al., 2020; Qiu et al., 2018; Jiang et al., 2022). Therefore, in line with what Wan, Cheng, and Tanaka (2016) emphasized, the participants were affected by the uncertainty in the initial decision phase, and they sought and monitored new alternatives in the re-decision phase and tended to change their answers.

Lastly, comparing the average RTs of consistent and inconsistent responses, the results indicate that for all response types (Yes, FOK, and No), participants' average RTs for inconsistent responses are significantly higher than average RTs for consistent responses. Reaction time is crucial for developing a deeper understanding of human memory processes. It provides valuable information about the information processing process (Theios, 1973). It is suggested that incongruent stimulus-response matches result in longer reaction times (Theios, 1973; Williams et al., 2007). Our results show that when participants review the responses that give during the decision phase and subsequently exhibit a tendency to change them, it results in longer reaction times. As expected, the findings support our third hypothesis. Researchers relate increases in reaction time to increased cognitive effortfulness, exploration of new alternatives related to the current situation, scanning of memory, shifting of attention and increasing of memory set (Theios, 1973; Hsieh, 2002; Williams et al., 2007).

4.3 Discussion for ERP Results

The findings of the ERP components obtained from two early components (N100, P200) and middle time window (250-500 ms), as well as two late time windows (400-650 ms and 651-900 ms), which were included in the statistical analysis, have been summarized and discussed under relevant subsections.

4.3.1 Discussion of N100 component findings. The N100 ERP component, which emerges approximately 90-200 ms after stimulus presentation during stimulus identification, is known to be associated with perceptual processing, attention, and working memory operations rather than the physical attributes of the stimulus. It is typically generated by the frontal cortex (Sur & Sinda, 2009; Horowitz-Kraus, 2014; Sokhadze et al., 2017). Lioumis et al.'s study (2009) reported the observation of the N100 component following transcranial magnetic stimulation of the left motor and

prefrontal cortex. On the other hand, Irak, Soylu and Turan's study (2019) revealed that FOK responses have higher amplitude values in midline channels. For the N100 component, hemispheric asymmetry was not observed in the studies (Pekkonen et al., 2002; Du et al., 2017). Also, the N100 component has been found to be associated with implicit learning (Hsieh et al., 2004), delayed memory task performance (Lijffijt et al., 2009), and working memory performance (Valdes et al., 2006).

The results of the regional and hemispheric comparison analyses indicate that there is no main or interaction effect for the "Yes" response. However, when examining the "FOK" responses, the regional comparison shows that the Pz and Cz electrodes exhibit higher amplitude values compared to the Fz electrode. This is inconsistent with the previous findings (Irak, Soylu & Turan, 2019). In Irak, Soylu and Turan's study, researchers indicated that amplitude values of "FOK" response is lower in Pz and Cz electrodes than Fz electrodes. Hemispheric comparison of "FOK" responses also indicate higher amplitude values in Cz and C2 electrodes. The larger amplitude at the central and left electrodes is consistent with previous findings when considering the use of a verbal material-based task (Dunn et al., 1998; Federmeier & Kutas, 2002; Wlotko & Federmeier, 2007).

Additionally, an interaction effect between decision type and channel location was observed for "FOK" and "No" responses separately. Results indicate that amplitude values at Fz and Cz electrodes are higher in the re-decision phase than the decision phase. Also, in the hemispheric comparisons of "No" responses, when looking at the frontal electrodes, the amplitude value in the re-decision phase is higher than the decision phase. According to Ghani et al.'s study (2020), the amplitude of the N100 component increases with task difficulty and the demand for more attentional resources. N100 is linked to the selective allocation of attention to the relevant stimulus and serves as an objective determinant in cognitive workload assessment (Ghani et al., 2020). The possibility of increased attentional resources might have contributed to the observation of a higher amplitude N100 component in re-decision phase. On the other hand, in the regional comparisons of "FOK" and "No" responses, the amplitude value at the Pz electrode is higher in the decision phase compared to the re-decision phase. Similarly, in the hemispheric comparisons of "No" responses, the amplitude of the decision phase is higher in the parietal electrodes than the re-decision

phase. In the study of Boutros et al. (2011) the N100 component observed in the parietal area was found to be associated with response suppression. Researchers suggested that a strong ability to suppress an irrelevant response elicits a high amplitude N100 component in the parietal region (Boutros et al., 2011). During the decision phase, participants engage in memory-based decision making and metacognitive evaluations in a context where both old and new stimuli are presented for the first time. Thus, when providing these responses for the first time, participants may have spent more effort to suppress irrelevant retrievals when performing memory scanning for situations where they could not reach the memory trace exactly ("FOK" and "No" response).

4.3.2 Discussion of P200 component findings. The P200 component is typically observed at fronto-central electrodes around 100-250 ms after stimulus presentation. This component, which is related to the task difficulty (Morrison, Kamal & Taler, 2019) is associated with attention allocation (Conley et al., 1999; Ciecko-Michalska et al., 2012), stimulus discrimination processes (Ghani et al., 2020), perceptual processing (Paynter et al., 2009), target detection (Luck & Hillyard, 1994). Additionally, the P200 component has been suggested to be related to top-down matching processing, monitoring the understanding of linguistic material, familiarity process (Federmeier et al., 2005; Evans & Federmeier, 2007; Federmeier et al., 2018; Federmeier, 2022). Indeed, Evans and Federmeier (2007) highlighted the association of the P200 component with implicit memory in their study on verbal materials and the old/new effect phenomenon (also see Rugg & Doyle, 1994). Also, Lefebvre et al. (2005) argued that the P200 component is a neurophysiological measure that can objectively assess working memory capacity.

As it is known that ERP components vary sensitively according to memory demands, considering the episodic memory task used in the current study, it appears that the P200 component is an important neurobiological marker for gaining insight into memory-based decision making and metacognitive processes. According to the study by Dunn et al., (1998) in a word recall task, when comparing participants with higher recall performance to those with lower recall performance, the P200 amplitude is higher at anterior frontal electrodes (e.g., Fz, F3 electrodes) and decreases towards

posterior electrodes, such as parietal and occipital electrodes. When examining the presence of a hemispheric distinction, researchers suggest that when stimuli are presented in the right visual field, the left hemisphere of the brain is prepared to use and process contextual information, and in such cases, the left hemisphere is hypothesized to utilize top-down attentional processing. As an outcome of this process, a larger amplitude P200 component is observed in the left hemisphere (Federmeier & Kutas, 2002; Wlotko & Federmeier, 2007).

As observed in the findings of this study, the larger amplitude in central and left electrodes in hemispheric comparisons is consistent with the literature, considering the use of a verbal material-based task (Dunn et al., 1998; Federmeier & Kutas, 2002; Wlotko & Federmeier, 2007). In the "Yes" response, no significant results were reported in regional comparisons, while significant channel location main effects were observed in "FOK" and "No" responses, with higher amplitude values in fronto-central electrodes compared to parietal areas, which is consistent with the proposition that P200 response originates from the fronto-central regions (Luck & Hillyard, 1994). The observed main effect of decision type for "FOK" responses indicates a decrease in P200 amplitude in the re-decision phase compared to the decision phase. This decrease in P200 amplitude in the re-decision phase may be attributed to increased test difficulty (Morrison, Kamal & Taler, 2019), cognitive and physical fatigue, and the potential negative impact of the repetition effect on familiarity processes (Jones, Childers & Jiang, 2012; Lee, Kim & Yi, 2020; Lange & Berry, 2021), considering the likelihood of the re-decision phase might be more challenging. As stated in the second hypothesis, contrary to memory-based decision making, metacognitive processes would be more involved during the "FOK" responses in the re-decision phase, since there is an inherent uncertainty in the "FOK" responses. And so, we expected a more pronounced difference between the two decision phases. However, for the more familiar "FOK" responses, a decrease in P200 amplitude is seen in the re-decision phase. As stated in the studies by Irak et al., (2019; 2020; 2023), the P200 component is suggested to be associated with perceptual fluency and the assessment of familiarity processes, serving as a guide for metacognitive processes. When deciding whether a items can be recognized in the future, it is characterized by the high amplitude P200 response, which is a rapid and effective evaluation of the items (Irak et al., 2019; Paynter, Reder

& Kieffaber, 2009). However, the re-presentation of the stimulus may have reduced the familiarity strength and made the mentioned assessment difficult. Therefore, the decreasing trend in P200 amplitude during the re-decision phase may positively correlate with the reduction in stimulus-specific familiarity (Paynter et al., 2009).

Finally, the significant decrease in amplitude at the Fz and Cz electrodes from the decision phase to the re-decision phase in "No" responses can be explained by the effect of task difficulty and cognitive bias. Participants may have made less effort to evaluate the item effectively and memory scanning, with the decreasing familiarity strength in the re-decision phase for the items for which they could not reach the memory trace in the initial decision phase. For the Pz electrode, the results showed that the P200 amplitude value in the decision phase was lower than the re-decision phase. Morrison, Kamal and Taler's (2019) study on WM capacity in young and old adults states that higher amplitude P200 component is observed in the parietal area in high WM performers compared to low performers. The low amplitude value in the decision phase in the parietal area can be explained by the difficulty of the task and the decrease in using effective WM capacity.

4.3.3 Discussion of middle time window ERP findings. The middle time window ERP findings were obtained by analyzing the mean amplitude values between 250-500 ms specifically for the frontal and central electrodes.

It is known that recollection and familiarity processes, which are said to contribute to recognition memory and suggested by dual process theory, are represented by different ERP components. Familiarity is generally associated with the FN400 component, which appears around 300-500 ms after stimulus presentation, particularly with a frontal scalp distribution (early mid-frontal old/new effect, Rugg & Curran, 2007). Curran et al. (2006) found that when participants gave a drug that would affect the source memory rather than the familiarity process, the parietal old/new effect (recorded at 500-800 ms at parietal regions), which was more related to the recollection processes for old stimuli, disappeared, but the FN400 component (recorded at 300-500 ms at frontal regions) was not affected by drug intervention.

It is stated that the correct rejection of newly presented stimuli and the accurate recognition of learned old stimuli (hits) during the encoding phase increase the FN400

mean amplitude value (Li & Nie, 2021). The increase in FN400 negativity when correctly rejecting new items, can be attributed to participants exerting more effort in retrieving associated information during the presentation of new items (Stróžak et al., 2016; Leynes et al., 2017). In the study by Park and Donaldson (2019), FN400 has been shown to be an effective neurobiological marker for the retrieval of relevant contextual information during recognition. The FN400 component, is particularly associated with the strength of familiarity, as reflected by ERP amplitude values at the left frontal electrode (also see Ecker & Zimmer, 2009; Stróžak, Abedzadeh, & Curran, 2016). But this situations differs when look at the studies that include the confidence rating for the responses (Woodruff, Hayama & Rugg, 2006; Roper, 2011). When the "old" response is given for old items reported with high confidence, it has been observed that the mean amplitude of FN400 exhibits a negative correlation with the confidence level: As the confidence increases, the FN400 amplitude decreases (Woodruff, Hayama & Rugg, 2006; Roper, 2011). This is interpreted to mean that when participants have high confidence in response, they will put less effort into memory scanning as they have a better degree of access to the memory trace. However, in the study of Addante, Ranganath, and Yonelinas (2012), it is emphasized that the amplitude of FN400 mean amplitude increases as the confidence level increases.

Mid-frontal FN400 components have been observed not only in memory-based decision-making studies but also in studies of metacognition. The Dunning-Kruger effect (DKE) phenomenon is interpreted in terms of metacognitive processes in studies using the FN400 component (Muller, Sirianni & Addante, 2021). In the DKE, individuals with poor performance tend to overestimate their abilities compared to others, whereas those with good performance tend to underestimate their abilities compared to others (Sieber, 1979). According to Muller, Sirianni and Addante (2021), different cognitive processes are suggested for over-estimators and lower-estimators. When the data of over-estimators is examined, an FN400-like component is observed, and it is interpreted as indicating an excessive familiarity process during overestimation. On the other hand, for lower-estimators, it is suggested that during the retrieval of information from memory, they rely more on recollection processes rather than familiarity (Muller, Sirianni & Addante, 2021).

The results of current analysis found no significant findings in comparisons between the decision and re-decision phase for any of the three response types. The significant channel location main effect observed for all three response types indicates that the mean amplitude value at the Fz electrode is higher than at the Cz electrode. This finding is in line with the literature suggesting a frontal scalp distribution for FN400 (Rugg & Curran, 2007). Hanczakowski et al.'s study (2013) shows that familiarity plays an important role in making metacognitive judgments of feeling-of-knowing and metacognitive monitoring, as well as in the memory-based decision-making process, and affects accuracy and confidence. When looking the mean amplitude values, "Yes" and "No" responses have higher amplitudes at the Fz electrode compared to "FOK" responses. Consistent with the study findings by Addante et al. (2012), FN400 mean amplitude in memory-based decision making ("Yes" and "No" responses) are higher amplitude compared to "FOK" judgments because of the responses that as a certain decision about whether the participants remember an item or not. On the other hand, this finding contradicts with studies emphasizing a positive correlation between strength of familiarity and amplitude of FN400 (Ecker & Zimmer, 2009; Stróžak, Abedzadeh, & Curran, 2016). Because the familiarity strength would be higher for the "Yes" and "FOK" responses compared to the "No" responses, and therefore the FN400 mean amplitude would be expected to be higher.

Lastly, the hemispheric comparisons showed that channel location main effect for "Yes" and "FOK" responses in frontal and central electrodes. Considering the use of word pair material and the literature indicating a stronger association of left frontal electrodes with familiarity (Woodruff, Hayama & Rugg, 2006; Ecker & Zimmer, 2009; Stróžak, Abedzadeh, & Curran, 2016), our results showing higher mean amplitude values in the left and midline electrodes compared to the right electrode are consistent.

4.3.4 Discussion of late time window ERP findings. The late time window findings were obtained by analyzing the mean amplitude readings within two specific time intervals (400-650 ms and 651-900 ms).

The late positive component (LPC), considered a neurobiological marker of recollective experience, is typically observed over the centro- parietal electrodes (especially left parietal) at approximately 400-800 ms after stimulus presentation (Curran, 2000). The amplitude of LPC shows a positive correlation with both recollection and high-confidence recognition (Addante et al., 2012). The amplitude of LPC has been found to be more positively associated with the accurate recognition of old items rather than the correct rejection of new items or false alarms (Kusak et al., 2000; Addante et al., 2012). In addition to these findings, LPC is also associated with memory retrieval (García-Larrea & Cézanne-Bert, 1998), response selection (Falkenstein et al., 1994), memory search (Okita, Wijers, Mulder & Mulder, 1985), cognitive effort (Matsuda et al., 2013), and inhibitory control (De Jong et al., 1990), working memory updating (Kusak et al., 2000), sustained attention (Gevins et al., 1996). Vilà-Balló and colleagues (2018) investigate the relationship between memory updating, a significant component of executive functions, and LPC. They used the N-back task and manipulated the task difficulty, demonstrating that the memory updating process, involving the maintenance and manipulation of information in working memory, can be influenced by task difficulty. Vilà-Balló and colleagues (2018) reported a higher LPC mean amplitude, particularly in the one n-back task, along with accurate recall and shorter reaction times. These findings are consistent with studies that show the association of LPC with task difficulty (García-Larrea & Cézanne-Bert, 1998). Moreover, fronto-central scalp distributed negative slow wave (NSW) has been found to be associated with memory scanning and the retention of duration in working memory (Ruchkin et al., 1995), also the manipulation and processing of visual materials (Kramer et al., 1986).

The regional comparisons conducted with ERP data obtained from the 400-650 ms time window show a channel location main effect for all three response types. The average mean amplitude values at frontal and parietal electrodes are higher than at central electrodes for all response types. However, while the mean amplitude value at Fz electrode is negative, it is positive in the parietal region. Although this finding is consistent with the NSW observed in frontal electrodes and the LPC observed in the centro-parietal area, it is unexpected that the average mean amplitude values are quite close for the three response types, representing different levels of memory retrieval.

According to Rösler et al. (1986), the LPC reaches its maximum degree in the centroparietal region under conditions where the stored information in memory is reactivated.

The hemispheric comparison results indicate a decision type main effect for "Yes" responses. Indeed, the average mean amplitude value of the re-decision phase at central electrodes is higher than the decision phase. It seems that, for the items with "Yes" responses in the re-decision phase, the opportunity to see stimulus again and reconsider of previous decisions may lead to a greater recollective experience and reactivating memory. As proposed by Theory 1 mentioned in the study of Qui et al., (2018) reconsidering and reviewing the decision in the re-decision phase, and monitoring the information in memory, more likely reflects the function of metacognitive processes. The involvement of metacognitive processes and working memory updating might have positively influenced the content of the recollective experience for "Yes" responses. On the other hand, it is observed that "No" responses also exhibit a higher LPC amplitude in the parietal area during the re-decision phase compared to the decision phase. This result is not consistent with the information available in the literature. The higher amplitude observed at parietal electrodes during the re-decision phase may be related to participants seeing the relevant stimulus again in the re-decision phase. Although participants report not remembering the pair of words, they review and reevaluate their previous decision. Remembering which response was given to the presented stimulus on the screen during the decision phase also reflects a recollective experience. Therefore, this pattern observed for "No" responses may be related to the recollection of previous presentations of the stimulus and the response given, differentiation between old and new stimuli, rather than the recollection of the pair of stimuli itself. Lastly, the channel location main effect observed in hemispheric comparisons is characterized by higher amplitude values in the left and middle channels, which is consistent with previous findings considering the nature of the task (Curran, 2000).

The regional comparison of ERPs obtained from the 651-900 ms time window reveals that the amplitude value in the decision phase is higher than in the re-decision phase for "Yes" responses. The amplitude value in the decision phase is negative, and it decreases in mean amplitude from anterior to posterior regions (and positive for

posterior electrodes). Düzel et al. (1997) state that the noetic awareness of mental time travel that subjects experience as part of their recognition experience is associated with NSW at the fronto-central electrodes. Furthermore, the NSW is also related to the memory scanning process (Ruchkin et al., 1995; Houlihan et al., 2004). In the decision phase, participants need to indicate first time their memory-based decision-making and metacognitive judgments, and for "Yes" responses, they may have more vividly retrieved their recollective experience and more performed memory scanning, than the re-decision phase. Besides, hemispheric comparison results revealed that for "Yes" responses, the mean amplitude value in the parietal electrodes during the re-decision phase was higher than the decision phase. This result can be explained by the possibility that the re-presentation of the stimulus set during the re-decision phase and the knowledge of the response given during the decision phase may lead to an increase and reactivate in the memory trace of the relevant stimulus (Rösler et al., 1986). We found the channel main effect in regional and hemispheric comparisons. The results show a negative amplitude value in the frontal region and a positive amplitude value in the centro-parietal areas in the late time window (Ruchkin et al., 1995; Curran, 2000). Also, consistent with previous findings, the left and middle electrodes are of higher amplitude compared to the right (Curran, 2000).

4.4 Conclusion

4.4.1 Conclusion of behavioral findings. The distribution of responses in the decision-re-decision phases was compared. It is thought that the higher mean value of the "No" responses in the re-decision phase can be explained by the negative effect of re-presenting the stimulus set during the re-decision phase on the source memory and the cost of reduced attentional resources for repeated stimulus presentations (Ranganath & Rainer, 2003; Kim et al., 2012; Lee, Kim & Yi, 2020; Lange & Berry, 2021).

When RT comparisons were examined, no significant difference was found between the decision-re-decision phases of the "Yes" responses, while the subjects needed longer RT in the re-decision phase for the "FOK" and "No" responses. It is thought that the subjects show more cognitive effort and therefore need more time

while giving the "FOK" and "No" answers in the re-decision phase (Tyler et al., 1979; Russo ve Doshier, 1983; Cooper-Martin, 1994).

Considering the means of the consistent and inconsistent responses, the inconsistent response in the "FOK" response was found to be bigger. Compared to memory-based decision making, this result, which is seen as an output of the uncertainty state of the "FOK" judgment due to its nature, may have tended to change responses more in the re-decision phase by being affected by the uncertainty level of the "FOK" responses, unlike memory-based decision making (Fleming et al., 2012; Wan, Cheng & Tanaka, 2016; Jia et al., 2020; Qiu et al., 2018; Jiang et al., 2022).

Finally, consistent with the third hypothesis, inconsistent responses have longer RTs than consistent responses. Changing the responses in the initial decision phase leads to the increased cognitive effort, discovery of new alternatives, re-scanning of memory, attention shifting to other options, and the participants need longer time (Theios, 1973; Hsieh, 2002; Williams et al., 2007).

4.4.2 Conclusion of ERP findings. Visual analysis shows that as suggested in the first hypothesis, the pattern of the ERP components of memory-based decision making and metacognitive judgment differ, especially in the middle and late time window. No differences in response types were observed in visual analyzes for the N100 and P200 early components. On the other hand, the mean amplitude of the FN400 component, which was emphasized to be associated with familiarity processes in the early time window, seems to be strikingly more pronounced for "FOK" responses. In addition, when the late time component, which is claimed to be related to the recollection process, is examined, the parietal old/new effect is more prominent in the "Yes" responses, especially for the parietal electrodes, compared to the "FOK" responses.

For all three response types, ERP components were observed in the decision and re-decision phases around 100, 200, and 250-500 ms time windows (N100, P200, FN400); additionally, ERP components emerged in the late time windows of 400-650 ms and 651-900 ms.

The component appearing at approximately 100 ms after stimulus presentation was associated with perceptual processing, attention, and working memory operations.

The interaction effect between the decision type and channel location detected for the "No" and "FOK" responses on the fronto-central electrodes showed that the N100 amplitude value at the Fz and Cz electrodes was higher in the re-decision phase. The increased attentional resources in the re-decision phase may have led to this result being observed. On the other hand, regional and hemispheric comparisons showed that the opposite situation for the Pz electrode may indicate that the subjects spent more effort to suppress irrelevant memory retrievals during the initial decision phase.

The second component that emerged at approximately 200 ms was proposed to be associated with attention allocation, stimulus discrimination processes, and perceptual processing. The lower P200 amplitude value in the re-decision phase of the "FOK" responses can be explained by the increase in the difficulty and fatigue of the task, and the decrease in the familiarity strength of the re-presentation of the stimulus. This decrease in the strength of familiarity may have made it difficult to evaluate the perceptual fluency and familiarity process. Also, it is thought that the lower amplitude values observed in the Fz and Cz electrodes for the "No" responses in the re-decision phase are due to the increase in the difficulty of the task and the cognitive bias of the subjects, thus making less effort to reach the memory trace. The lower amplitude value at the Pz electrode in the decision phase was associated with the possibility of ineffective using the WM capacity.

The middle time window revealed the FN400 component, which was found to be associated with familiarity strength. Neither regional nor hemispheric comparisons demonstrated the presence of the decision type main effect for any response type which was not expected. Familiarity is associated with making metacognitive judgments of feeling-of-knowing and monitoring, the memory-based decision-making process and affects accuracy and confidence. Therefore, the direction of expectation was that if metacognitive processes were more involved in the re-decision phase, as suggested by previous studies, would see a significant difference between the decision phases (Qui et al., 2018; Jiang et al., 2022).

Finally, the ERP components obtained from the late time window, particularly the centro-parietal LPC, were associated with recollection, whereas the fronto-central NSW is associated with memory scanning and duration retention in working memory. The main effect of decision type was observed in the 400-650 ms time window in the

hemispheric comparison, showing a decision type effect for "Yes" responses at central and "No" at parietal electrodes. Considering "Yes" response, it was thought that when the participants were allowed to make a decision again, thinking about previous decisions might have increased recollective experience and led to memory reactivation. The high mean amplitude value in the re-decision phase of "No" responses may be related to the recall of previous presentations of the stimulus and the response, the distinction between old and new stimuli, rather than remembering the stimulus pair itself.

In the 651-900 ms time window, decision type main effect was found for "Yes" responses in the regional and hemispheric comparisons. The fact that the mean amplitude value of the subjects was higher and negative at the initial decision stage was interpreted as more vivid recollective experiences and more effort for memory scanning (Ruchkin et al., 1995; Houlihan et al., 2004). The difference observed in the parietal region is thought to be related to the increased and reactivated memory trace of LPC with higher mean amplitude in the re-decision phase (Rösler et al., 1986).

In summary, as stated in the first hypothesis, visual analysis showed that there were topographical differences in the ERP components revealed by memory-based decision making and metacognitive judgment. Moreover, as stated in the second hypothesis, the comparisons between the decision phases provided evidence the main decision type effect in some ERP components.

4.5 Strengths and Limitations of the Study

According to the literature, this study is the first to examine the temporal dynamics of memory-based decision-making and metacognitive judgment in a joint paradigm involving both decision and re-decision phases. Furthermore, the study's sample is extensive, and its high representativeness increases the generalizability of the findings to the relevant population (Royall, 1986). While there are neuroimaging studies that investigate memory-based decision-making and metacognitive judgment together (Qui et al., 2018; Jiang et al., 2022), ERP/EEG studies in this area are quite limited, and it is believed that this current study will contribute to the existing literature. Interpreting resolution techniques together is considered valuable for understanding these processes. Furthermore, the contribution of the current study to

the literature can be precious in understanding the difficulties experienced by patients with obsessive-compulsive disorders (Ress & Anderson, 2013), schizophrenia (Lysaker & Dimaggio, 2014), Alzheimer's (Hallam et al., 2020), and Parkinson's diseases (Lenzo et al., 2020) in memory-based decision making and metacognitive processes. It may also aid in developing of effective rehabilitation programs for these conditions.

In addition to the strengths, the current study also has some limitations. During data collection, a high level of noise was observed despite the low impedance values, particularly in the anterior frontal electrodes, leading to their exclusion from the topography and analyses. The participants provided their metacognitive judgments by pressing the "FOK" button. In previous studies, the FOK judgment has been evaluated using a 6-point Likert scale (Hart, 1965; Nelson & Narens, 1994; Irak et al., 2023) or a 3-point scale (Baran et al., 2009; Güler et al., 2020). Using a single option has led to the cumulative consideration of high and low FOK judgments. However, it is considered important for future research to separately analyze high and low FOK judgments to provide comprehensive information about metacognitive judgments.

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