

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

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**INVESTIGATING THE NEUROPHYSIOLOGICAL FOUNDATIONS OF
JUDGMENT OF LEARNING: AN EVENT-RELATED POTENTIAL STUDY**



MASTER'S THESIS
SONER YUCETEPE

BAU 2023

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THESIS ADVISOR
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MASTER THESIS APPROVAL FORM

Program Name:	Cognitive Neuropsychology
Student's Name and Surname:	Soner Yücepepe
Name of The Thesis:	Investigating the Neurophysiological Foundations of Judgment of Learning: An Event-Related Potential Study
Thesis Defense Date	02.08.2023

This thesis has been approved by the Graduate School which has fulfilled the necessary conditions as Master thesis.

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ABSTRACT

INVESTIGATING THE NEUROPHYSIOLOGICAL FOUNDATIONS OF JUDGMENT OF LEARNING: AN EVENT-RELATED POTENTIAL STUDY

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Cognitive Neuropsychology Masters Program

Thesis Advisor: Prof. Dr. Metehan IRAK

July 2023, 43 pages

The ability to monitor the memory and learning processes is crucial for the adaptive behavior. Judgment of Learning (JOL), one of the metacognitive judgments, is commonly used to assess this ability. Different hypotheses have been suggested regarding the cognitive mechanisms underlying this process and its relationship with memory. This study aims to investigate the neural correlates of JOL with event-related potential (ERP) methodology. Seventy-two young adults participated in an episodic memory task involving word-pairs as stimuli. ERP components were compared for distinct JOL levels. Moreover, ERPs for the hit responses in the recognition test were also compared within themselves according to the JOL levels assigned to them. The analyses for the former comparison showed that JOL processes are observable within early time window after stimulus presentation. The P100, N100, P200, N200, and P300 components were found to be elicited for distinct JOL levels, but only N100 did vary in amplitude among those levels. Additionally, a negative component with 330-500 ms latency was also evident for distinct JOL levels and did not differ in amplitude among the levels. The analyses for the recognition phase ERPs showed that different types of hit responses did not show a significant difference in the familiarity-related mid-frontal effect (FN400) amplitude, however those assigned high level of JOL elicited recollection-related parietal old-new effect with smaller amplitude. These results support the hypothesis that JOL is influenced by familiarity and the degree of access to information.

Keywords: Judgment of Learning, Metamemory, Episodic Memory, Event-Related Potential.



ÖZ

ÖĞRENME KARARININ NÖROFİZYOLOJİK TEMELLERİNİN İNCELENMESİ: BİR OLAY-İLİŞKİLİ POTANSİYEL ÇALIŞMASI

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Bilişsel Nöropsikoloji Yüksek Lisans Programı

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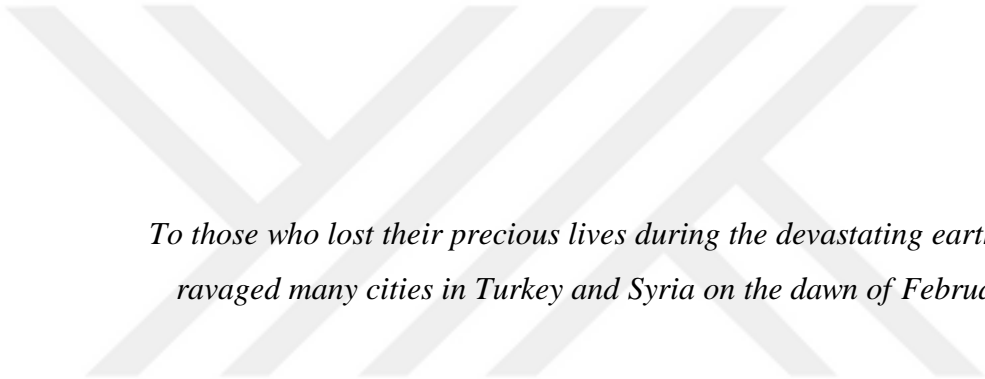
Temmuz 2023, 43 sayfa

Bellek ve öğrenme süreçlerini izleme becerisi uyumlayıcı tür davranışlar için çok önemlidir. Üstbilişsel karar türlerinden biri olan Öğrenme Kararı (ÖK), bu becerinin değerlendirilmesinde sıklıkla kullanılmaktadır. ÖK'nin ve bu üstbilişsel sürecin bellekle ilişkisinin altında yatan bilişsel mekanizmalara dair farklı hipotezler öne sürülmüştür. Bu çalışmada, Olay-İlişkili Potansiyel (OİP) yöntemi kullanılarak ÖK'nin nöral temsillerinin incelenmesi amaçlanmıştır. Uyarı olarak kelime çiftlerinin kullanıldığı bir olaysal bellek görevine yetmiş iki genç yetişkin katılmıştır. Farklı ÖK düzeyleri için OİP karşılaştırmaları yapılmıştır. Ayrıca, tanıma testindeki doğru yanıtlar, kendilerine verilen ÖK derecelerine göre kendi içinde karşılaştırılmıştır. İlk karşılaştırma için yapılan analizler, ÖK süreçlerinin uyaran sunumundan sonra erken zaman penceresinde gözlemlenebilir olduğunu göstermiştir. Farklı JOL düzeylerinin P100, N100, P200, N200 ve P300 bileşenlerini ortaya çıkardığı bulunmuştur, ancak yalnızca N100 ÖK düzeyleri arasında genlik açısından farklılaşmıştır. Ayrıca, farklı ÖK düzeyleri için 330-500 ms arasında negatif bir bileşen ortaya çıktığı görülmüş ancak bu bileşenin düzeyler arasında genlik açısından farklılık göstermediği bulunmuştur. Tanıma testi aşamasından elde edilen OİP'ler ile yapılan analizlerde ise, doğru yanıt türleri arasında aşinalık ile ilişkili olan orta frontal etki (FN400) genliği açısından anlamlı bir farklılık olmadığı görülmüştür. Ancak yüksek düzeyli ÖK'ye verilen doğru yanıtların hatırlama ile ilişkili parietal eski-yeni etkisini diğer doğru yanıt türlerine göre daha küçük genlikle ortaya çıkardığını göstermiştir.

Bu sonuçlar, ÖK'nin yalnızca aşinalıktan değil, aynı zamanda bilgiye erişimin derecesinden de etkilendiđi yönündeki hipotezi desteklemektedir.

Anahtar Kelimeler: Öğrenme Kararı, Üstbellek, Olaysal Bellek, Olay-İlişkili Potansiyel.





To those who lost their precious lives during the devastating earthquake that ravaged many cities in Turkey and Syria on the dawn of February 6, 2023.

ACKNOWLEDGMENTS

First and foremost, I would like to express my sincere appreciation to my thesis advisor, Professor Metehan Irak. I am thankful to him for his guidance and invaluable support, throughout this transformative academic journey. Not only did he provide supervision during critical stages but also, he's always been there during the most challenging moments. Undoubtedly saying, it was a privilege to be mentored by such a distinguished scholar.

I would like to extend my gratitude to Assistant Professor Hale Ögel Balaban for the insights she provided during the first year of my master's program, also for her contributions to my thesis as a member of my committee. I would also like to thank the esteemed Professor Canan Başar Erođlu for her seminal contributions in accepting to be part of my committee.

I would very much like to thank my lab colleagues. This study could not have been done without them. They have demonstrated to me the significance of teamwork through this collaboration.

Special thanks to my wonderful classmates. Our communication has never ceased since the day we met. Our profound exchanges, encompassing a myriad of topics, have consistently nourished me. I have learned too much from them, particularly in cultivating a resolute sense of solidarity in every difficulty.

The greatest of my thanks are to my darling mother, Güllü Açıkgöz. Words fail to capture the depth of my appreciation for her immeasurable support. If by any means I can reciprocate the boundless generosity she has bestowed upon me, I consider myself fortunate. Nothing would have been possible without her.

This study was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK). On this occasion, I would like to express my infinite gratitude to TÜBİTAK for providing this opportunity, as well as to all the participants who volunteered to the study.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
DPT	Dual-Process Theory
EEG	Electroencephalography
EOG	Electrooculography
EOL	Ease of Learning
ERP	Event-Related Potential
FOK	Feeling of Knowing
JOL	Judgment of Learning
LPN	Late Posterior Negativity
LTM	Long-Term Memory
vmPFC	Ventromedial Prefrontal Cortex
MINI	Mini International Neuropsychiatric Interview
MTC	Medial Temporal Cortex
OİP	Olay-İlişkili Potansiyel
RT	Reaction Time
STM	Short-Term Memory

Chapter 1

Introduction

Metacognition is defined as one's knowledge about their own cognitive processes (Flavell, 1976). It is employed to convey the understanding of how one perceives, comprehends, remembers, thinks, and acts (Metcalfe & Shimamura, 1994). An individual's awareness, for instance, that they learn better through listening rather than reading, or their acknowledgement that they have not sufficiently learned the topics that they are responsible for an upcoming exam can be considered as metacognitive knowledge. However, metacognition not only refers to one's awareness of their own cognitive processes, but also their ability to regulate and control these processes (Reeve & Brown, 1985; Leader, 2008; Thenmozhi, 2019). Nelson and Narens (1990) proposed a model which outlines how individuals organize their knowledge about their own cognition, but also how to control it. According to this model, there are two levels in terms of the relationship between cognition and metacognition: *object-level* and *meta-level*. The object level is at where individuals perform cognitive actions (e.g., attempting to memorize a poem), whereas the meta-level involves a representation of the cognitive actions ongoing at the object level (e.g., reflecting on how well the poem memorized). A constant flow of information facilitates communication between these two levels, with two distinct processes determined by the direction of the flow: *monitoring* and *control*. Monitoring is activated when information flows from the object level to the meta-level, providing individuals with knowledge about their cognitive actions. This, in turn, enables individuals to initiate, regulate, maintain, or terminate the cognitive actions, with information flowing from the meta-level to the object level, activating the control process.

Brown (1978) has posited that metacognitive monitoring and control maintain a record of ongoing activities within the memory system. As discernible from its definition, metacognition also enables one to monitor and control the cognitive processes related to their memory. This is what it has been called as metamemory that one possesses the knowledge regards to their own memory processes, including encoding, storage, and retrieval, and the ability to control these processes (Flavell, 1971). Metamemory, in fact, is the awareness of the individual that determines how to

allocate study time in learning processes, which strategies to use, and when to terminate the study. In terms of such applied interests, metamemory has been considered a very crucial ability (Sommer et al., 1995).

There are two types of monitoring regarding metamemory that can be distinguished: retrospective and prospective monitoring. Retrospective monitoring is associated with recognition and recall in classical memory processes. Prospective monitoring begins after the completion of retrospective monitoring (the occurrence of a response). Nelson and Narens (1990) have categorized prospective monitoring into three groups: ease of learning (EOL), feeling of knowing (FOK), and judgments of learning (JOL).

Individuals acquire information about the difficulty of the study material before engaging into the learning process. This assessment is made through metacognitive monitoring that is referred to as EOL (Nelson & Narens, 1990; Jönsson & Lindström, 2010). EOL plays a significant role in determining the allocation of time to the study material, also deciding which material should be learned first and the next (Jönsson & Lindström, 2010; Mazzoni et al., 1997). Individuals can also engage in prospective monitoring during, or after, the learning process. For instance, even if they cannot immediately answer a question related to the material they have learned, they may still have a sense of knowing the answer, which is referred to as FOK (Modirrousta & Fellows, 2008; Nelson & Narens, 1980). FOK is concerned with the extent to which items that cannot be currently recalled could be recognized in a future memory test (Irak, 2005, 2009; Irak et al., 2019).

Prospective monitoring related to memory can also be made through JOL which is frequently studied considering the functions of metamemory (Bui et al., 2018; Souchay et al., 2004; Jersakova et al., 2017). Since it is the focus of the study, this judgment is explained under a separate heading below.

1.1 Judgments of Learning

JOLs are the assessments that reflect the estimates of the memorability of studied items and whether they can be remembered in a subsequent memory task (Dunlosky & Nelson, 1992; Nelson & Narens, 1990). Considering this definition, JOL encompasses both past and future temporal components. That is, JOL can be performed through retrospective monitoring as well as prospective monitoring. For

instance, following the learning, JOL may include the assessment of past knowledge (e.g., “How well did I learn it?”), but also the estimate of future retrieval (e.g., “Will I be able to remember it later?”).

Different hypotheses have been suggested regarding the cognitive processes underlying these metacognitive judgments. One of them is the *direct access hypothesis* which suggests that these judgments are made by directly reaching the memory trace of the information in question (Schwartz, 1994). It is assumed that direct access to the target information becomes more accessible with the increase in the strength of the memory trace (Koriat, 1997; King et al., 1980). On the other hand, the *cue-utilization hypothesis* proposes that JOL is based on the using different cue sources rather than assessing the strength of the memory trace. These cue sources may be the beliefs about one’s own memory (Hertzog et al., 1990), learning strategies that were previously developed (Begg et al., 1991), expectations about the memory test (Mazzoni et al., 1990), or the perceived difficulty of the study materials (Arbuckle & Cuddy, 1969). These two hypotheses offer diverse perspectives about the relationship between JOL and memory functions. Considering the direct access hypothesis, the stronger memory trace of the information, the higher level of JOL to be made regarding that information. However, considering the cue-utilization hypothesis, JOL is made instead of accessing the memory trace directly, with the support of currently available cues, which indicates that there might be a separate process for JOL from memory (Koriat, 1997).

1.2 The Relationship Between JOL and Memory Processes

To understand the relationship between JOL and memory processes, it is pivotal to investigate the accuracy of JOLs. If JOL is, for instance, based on direct access to the memory trace, it is plausible to expect higher accuracy. However, it has commonly been suggested in the literature that the accuracy of these judgments is affected by the time between encountering the stimuli and making JOL for them (Kimball & Metcalfe, 2003; Rhodes & Tauber, 2011). If JOL is made right after the presentation of the stimuli it is called immediate JOL, whereas if it is made after a while, it is called delayed JOL. A widespread finding is that the accuracy of judgments made in the delayed JOL condition is higher than those made in the immediate JOL condition (Bui et al., 2018). Different hypotheses have been put forth regarding this phenomenon, including the *dual memories hypothesis* proposed by Nelson and Dunlosky (1991). This hypothesis highlights the role of short-term and long-term

memory processes for JOL. In the immediate JOL condition, the relatively more accessible and dominant memory type is short-term memory (STM), so the assessment of the target information for JOL is made through the information stored in STM. However, the information stored in the STM might no longer be accessible in a subsequent recall or recognition test.

On the other hand, in the delayed JOL condition, a certain period passes after learning, making the use of information in long-term memory (LTM) more dominant. Since the information stored in LTM is still accessible, LTM-dominant JOL's accuracy is higher than the accuracy of STM-dominant JOL (Dunlosky & Nelson, 1992). Metcalfe and Finn (2008) stated that JOLs made in delayed condition are more accurate since they first require a rapid assessment of familiarity, and if the detected familiarity level is high enough, an attempt is made for retrieval and JOLs are performed accordingly. Also, it has been reported that decreased JOL judgments are associated with longer reaction time and difficulties in the retrieval process (Son & Metcalfe, 2005).

Another hypothesis proposed for the delayed JOL phenomenon is the *self-fulfilling prophecy* approach (Spellman & Bjork, 1992). According to this perspective, while one makes JOL in the delayed condition, that judgment would be grounded in an implicit retrieval experience. If one can successfully retrieve the target information, they would provide a high level of JOL; however, if they fail to retrieve it, they will report a low level of JOL. Consequently, their experience in this condition would inevitably overlap with their performance on the memory test.

Lastly, the *transfer-appropriate monitoring* hypothesis explains this phenomenon based on the match between the context in which individuals make JOLs and the context in which they are tested (Morris et al., 1977). According to this hypothesis, in a paradigm using word pairs (cue-target), for example, if participants are presented only with cue words during both the study and test phases, their JOL ratings will be higher compared to a condition where cue and the target words are presented together during the study phase, but only the cue words are presented during the test phase.

Within the framework of these hypotheses, a meta-analysis comparing accuracy and memory performance in the immediate and delayed JOL conditions

found that judgments made under the delayed JOL condition showed greater accuracy compared to those made under the immediate JOL condition (Rhodes & Tauber, 2011). Further, it has been reported that as the delay increases, accuracy also increases. Moreover, the match between the study and test phases has been found to enhance accuracy. These results support all the accounts suggested for the delayed JOL phenomenon. However, analyses for memory performances showed that although better performance was still evident in the delayed JOL condition compared to the immediate JOL condition, the effect sizes in these analyses were much smaller than those observed for accuracy analyses. This observation accentuates the significance of the research question of the present study regarding the relationship between JOL and memory processes.

Another meta-analysis by Luna et al. (2018) examined the effect of perceptual characteristics of the stimulus on JOL ratings and memory performance, depending on whether JOL was performed in the immediate or delayed conditions. The fundamental assumption of the study was that some properties of the study materials may affect memory while not necessarily affecting metamemory, or vice versa. From this point of view, they conducted the study which is based on the hypothesis that although perceptual characteristics of the stimulus can decay quickly, they may cause an illusion on the JOL ratings in the immediate JOL condition, while such an effect will manifest to a lesser extent in the delayed JOL condition. Results supported the hypothesis, showing that the average JOL ratings in the delayed JOL condition were lower than the immediate JOL condition. Moreover, the accuracy in delayed JOL condition was higher than the immediate JOL condition. Another study also showed the effect of perceptual characteristics of stimulus on JOL ratings in which words in small fonts (8 points) and large fonts (48 points) were presented to the participants, and they were asked to make immediate JOLs for each of these words (Rhodes & Castel, 2008). The results showed that JOL ratings for words displayed in large font were higher, but no correlation was found between stimulus size and memory test performance. In another following study, participants were presented with stimuli in the auditory modality. The analyses of the JOL ratings and accuracy of the responses to the stimuli, some of which were high in volume whereas some were low, showed similar results; JOL ratings were higher for stimuli presented in high volume, but no correlation was found between stimulus volume and memory test performance (Rhodes & Castel, 2009). Such impacts

of the perceptual characteristics of the stimuli on JOL and memory processes have been further supported by subsequent studies (Tatz & Peynircioğlu, 2020; Tatz et al., 2020; Undorf et al., 2018).

1.3 Neurocognitive Aspects of Judgment of Learning

The hypotheses mentioned above for the delayed JOL phenomenon seem to be supported by the findings, which point to a retrieval attempt during the delayed JOL condition. On top of that, there are studies providing neuroscientific evidence to support these hypotheses as well. For example, Kelley et al. (2021) showed images of scenes, faces and objects to nineteen participants, and asked them to choose the category among these for each stimulus they saw. While the participants making these assessments, the representations in their brains were imaged with fMRI. Next, the participants saw image pairs (cue-target) such as “an object and a face”, “a face and a scene”, or “an object and a scene”. For these pairs, either in the immediate JOL condition or in the delayed JOL condition, only the cue stimulus was shown, and they were asked to make JOL for the target stimulus. The brain activations of the participants while making JOL was also scanned. It was found that the activation during JOL was significantly more similar in the delayed JOL condition compared to the immediate JOL condition with the regions activated for the same target category in the first phase. That is, the participants are much more likely to experience retrieval of the target information in the delayed JOL condition. Do Lam et al. (2012) also supported that there might be a retrieval attempt in the delayed JOL condition with the finding of hippocampal activation while the participants made JOLs for the items which were successfully recalled in the memory test.

Although these findings indicate that individuals make JOLs by retrieving the information from memory, that might be the case to some extent since it is unclear whether these retrieval attempts are the only basis. Indeed, other neuroimaging studies offer different findings in this regard. For example, Kao et al. (2005) found in their fMRI study, in which they compared the neural correlates of JOL and memory processes, that the medial temporal cortex was active in memory-related processes but not in JOL-related processes. On the other hand, while the ventromedial prefrontal cortex was active in JOL-related processes, it was not active in memory-related processes. Similar results have been reported in other studies examining the relationship between JOL and memory processes with fMRI (Andrés et al., 2010;

Vilkki et al., 1999). However, this difference between these two processes has not been extensively examined in terms of temporal resolution. Some of the event-related potential (ERP) studies, although there are not many, investigated this relationship between JOL and memory. In one of these studies (Sommer et al., 1995), the ability to estimate future recognition performance for faces was investigated. Twenty-four participants were divided into two groups, one group was asked to provide distinctiveness (distinctive or typical) ratings for presented faces and the other group asked to provide JOL ratings. These two conditions served to see if the recognition prediction for faces (JOLs) are based on a perceptual characteristic such as distinctiveness. Both groups rated the faces on a 4-point scale. In the following test phase, participants were asked to indicate whether they had previously seen the presented stimuli (old/new judgment). ERPs were averaged according to the following conditions: (i) subsequently recognized or unrecognized faces presented during the first stage, (ii) faces rated with the high JOL vs low JOL, (iii) faces rated with the high distinctiveness vs low distinctiveness, and finally (iv) old vs new judgments in the recognition phase. The results showed that ERPs for subsequently recognized faces were more positive in anterior sites and more negative in posterior sites compared to those for subsequently unrecognized faces, in both groups. ERPs for JOL and distinctiveness ratings were also obtained, and these ERPs showed similar effects with the ERPs obtained for the first condition especially between 300-500 ms. Further, “subsequently recognized minus subsequently unrecognized” responses were compared with “high JOL minus low JOL” responses and “high distinctiveness minus low distinctiveness” responses. The results showed that all three effects produced similar responses, with more positive responses in anterior sites and more negative responses in posterior sites between 300-500 ms. However, difference waves obtained for JOL and distinctiveness ERPs differed from “subsequently recognized minus subsequently unrecognized” ERPs between 500-1000 ms. Moreover, behavioral analyses yielded better recognition performance for faces rated as “high JOL” compared to those rated as “low JOL”, and for faces rated as “distinctive” compared to those rated as “typical”. Last but not least, it was found that the correlation between JOL and recognition decreased to a non-significant level when controlling for distinctiveness. Therefore, these results provide evidence that distinctiveness of a face may influence the prediction of future recognition performance (JOL) which implies that JOL may be a distinct process from memory.

Skavhaug et al. (2010) aimed to compare the neural correlates of JOL and successful memory encoding processes. Twenty undergraduate students were presented with word pairs (cue-target) and asked to rate the recallability of the target on a 5-point scale. Their memory performance was tested using cue words and new words in a recall task. EEG (Electroencephalography) recordings were collected only during the study phase, from which ERPs were derived for two distinct conditions: (i) responses related to subsequently recalled and missed words during the test phase, (ii) high and low JOL responses. In the analyses comparing the subsequent memory contrast and JOL contrast effects, a similar distribution in both was found in the 550-1000 ms time window, with positivity which has the highest amplitude in the midline. However, in the late time window (1300-1900 ms), a JOL contrast-specific negativity appeared in the left central electrodes, which was not present in the memory contrast. This response was more pronounced for high JOL responses. The authors interpreted the results as indicating that JOL and memory processes have partially distinct neural generators. They also suggested that the difference between high and low JOL responses in the late time window may be attributed to access to information for high JOL responses but not for low JOL responses. In a later study, the authors tested this explanation using dual process theory (DPT) (Skavhaug et al., 2013).

According to DPT for memory, successful recognition involves two distinct processes: familiarity and recollection (Yonelinas, 1994). Recollection refers to retrieving specific contextual information about studied materials, while familiarity refers to the feeling of having encountered the material before (Yonelinas, 2002). ERP studies on dual process of memory reveal an early (300-500 ms) mid-frontal negativity known as the FN400 (mid-frontal) old/new effect, associated with familiarity and a subjective sense of “knowing” the previously encountered material. Additionally, a later (400-800 ms) parietal positivity called the parietal old/new effect is associated with recollection and a subjective sense of “remembering” contextual information in recognition memory (Curran, 2004). Rugg et al. (1998) showed that the FN400 old/new effect did not differentiate for shallowly and deeply encoded words, but the parietal old/new effect elicited only for deeply encoded words. Moreover, Curran (2004) examined how these two effects differ as a result of manipulation of attention (full, divided). It was found that the FN400 old/new effect was similar in magnitude

under both full and divided attention conditions however, the parietal old/new effect was greater in the full attention condition.

Based on this literature, Skavhaug et al. (2013) tested the hypothesis which implied in their previous study whether JOL is related to recollection or familiarity. Twenty-four undergraduate students rated word pairs (cue-target) on a 5-point JOL scale. In the test phase, they performed an old/new recognition task, recalling target words for the cues judged as old. EEG recordings were taken during the test phase, and ERPs were derived for the hit responses. These responses were compared for the conditions where the participants provided a high or low JOL during the study phase. ERP analyses showed that FN400 old/new effect (at F3 and F4 electrodes) was observed for all words that were successfully recognized (with high JOL or low JOL responses). Additionally, this effect was elicited of equal magnitude for words with both high and low JOL responses. However, the later parietal old/new effect differed: high JOL responses elicited a more positive-going response in the left posterior areas (at P3 electrode) compared to low JOL responses. Authors stated that these electrophysiological data support the view that participants rely on contextual details and recollection process while providing especially high JOL responses. Therefore, it is possible to make an interpretation on the difference between high and low JOL responses, as suggested in their previous study (Skavhaug et al., 2010). Such interpretation is also supported by a behavioral study examining the relationship between JOL, familiarity, and recollection processes. Participants saw individual words and made JOL for each of them. The results obtained by using the remember/know paradigm, showed that words with high JOL responses more attracted remember responses, which is known to measure recollection, than the words with low JOL responses (Daniels et al., 2009).

In another study (Müller et al., 2016), eighteen participants were presented with single pictures. These pictures were coupled (cue-target) and presented once again. Participants made judgments in two conditions: one for JOL, and the other for a decision whether the color yellow was present in the picture pair, serving as a memory-related control condition for ERP comparison. As observed in the study of Skavhaug et al. (2010), a positive slow wave was observed in frontal electrodes and a negative slow wave in posterior electrodes. However, JOL responses were found to be diverge from the control condition responses in an earlier time window (350-700 ms) rather

than the late time window (1300-1900 ms). The authors explained this difference by highlighting the delayed JOL condition in the experiment. Participants, due to the delay, did not need to spend additional time on picture identification or memorization during the JOL phase, and could directly engage in the task of making JOLs.

A more recent study (Undorf et al., 2020) examined the effect of processing fluency on JOL using the N400 ERP component. The N400 is considered an index of processing fluency, responding to semantically unrelated stimuli. Twenty participants rated the recall probability of target words on a scale from 0 to 100 in immediate JOL condition after being presented with related and unrelated word pairs (cue-target). They were then tested for their memory performance. Following a short break, a second study-test session was conducted. Memory performance and JOL ratings were higher for related word pairs compared to unrelated word pairs in both study-test sessions, however JOL ratings were found to be higher than in the first session. The amplitude of N400 was greater for unrelated word pairs in the first session, but this difference disappeared in the second session. However, the effect of relatedness on JOL ratings remained consistent across sessions. In other words, participants consistently assigned higher JOL ratings to related word pairs in both the first and second sessions. These results highlight the influence of processing fluency on JOL and suggest that JOL is inferential in nature. This is also suggested by the cue-familiarity hypothesis that familiarity with the information is more important than the trace of that information in the memory while making metacognitive assessments (Reder, 1987). Reder and Ritter (1992) conducted experiments involving questions related to mathematical operations, and asked participants whether they knew the answers (i.e., being able to provide the answer at that moment) or if they needed to perform calculations to find the answer. The results revealed that participants' responses to the questions varied as the exposure frequency (i.e., familiarity) to those questions increased. Based on these and subsequent similar studies, it was emphasized that metacognitive assessments can be based on the familiarity with the questions rather than how well the answers are known (Klin et al., 1997). This suggests that individuals primarily engage in a rapid assessment when making estimations related to their memory. Indeed, Paynter et al. (2009) employed a similar paradigm in their study, conducting ERP analyses and observing components related to metacognitive processes as early as 200 ms after stimulus presentation. The P200 and P300

components showed increased amplitudes as the level of stimulus familiarity increased. These early ERP responses were associated with familiarity-related mid-frontal effects. Therefore, if estimations related to memory performance are performed in a familiarity-based manner, early components (within 200-300 ms) are expected to be observed. However, if the components also emerge at a later time window (after 300-400 ms), it can be inferred that the process is more recollection-based.

1.4 The Goal of the Study

The theoretical explanations regarding JOL present different perspectives for the underlying cognitive mechanisms of this metacognitive judgment. Neuroscientific methods provide rich opportunities for the investigation of these approaches. However, there is a limited number of studies that investigated JOL using the EEG/ERP methodology, which offers significant advantages in terms of temporal resolution. Those limited number of studies indicate that JOL is associated with a negative slow wave elicited in the posterior region and a positive slow wave in the anterior region with 350-700 ms (Müller et al., 2016). This observation, derived from a paradigm that employed images as stimuli, was interpreted as the retrieval of information and its maintenance in visual working memory. Other ERP studies on metacognitive processes have also indicated that ERP components elicited after early time window (after 400 ms) can be associated with a recollective experience (Metcalfe & Dunlosky, 2008; Melcalfe & Finn, 2008). Nonetheless, it has also been noted that earlier ERP components related to familiarity (within 200-300 ms) can also be observed in relation to metacognitive judgments (Paynter et al., 2009), as was evident in a previous EEG study conducted in our laboratory as well. In that study, a face-name recognition paradigm was used to investigate the neural correlates of JOL and FOK. Consistent with previous findings, ERP results for JOL responses revealed a late time window (300-700 ms) negative component at posterior electrodes. High JOL responses showed greater amplitude compared to low JOL responses, although this difference was not statistically significant. Additionally, both high and low JOL responses elicited earlier time window ERP components including N100, P100, N170, N200, P200, and P300 (Irak et al., 2020). These findings indicate that the neural correlates of JOL can be observed approximately 200 ms after the stimulus presentation.

It should be noted that metacognitive judgments are task sensitive. Therefore, it is of great importance to conduct research on these processes using diverse materials and paradigms. In the present study, we aimed to investigate the neural correlates of JOL during an episodic memory task, employing a paradigm where word pairs served as stimuli in a delayed JOL condition. Moreover, in contrast to previous studies, we measured the JOL with categoric choices rather than Likert or other types of rating scales. For this aim, the ERPs for the distinct JOL levels were averaged. Additionally, we also aimed to see whether the mid-frontal old/new effect and the parietal old/new effect in the subsequent memory test would differ based on the level of JOL. Therefore, ERPs for correct recognitions (hit responses) were also averaged after separating them into distinct JOL levels assigned in the JOL phase. Finally, JOL responses compared within themselves in terms of reaction time and recognition performance.

As previous studies suggested (Irak et al., 2020; Paynter et al., 2009), it is hypothesized that ERP components associated with familiarity in the early time window (within 200-300 ms) will be observed. Since JOLs were made in the delayed JOL condition in the present study, it is hypothesized that distinct JOL levels will not differ in terms of the amplitudes of these ERP components elicited within that time window. Additionally, consistent with previous findings (Irak et al., 2020; Müller et al., 2016), it is expected that a negative slow wave, which is elicited after 300 ms, will be elicited with higher amplitude for high level of JOL compared to other levels.

Moreover, when the ERPs for the hit responses in the subsequent recognition test are compared after separating them into distinct JOL levels, no significant difference is expected in the amplitude of mid-frontal old/new effect between responses, whereas the parietal old/new effect is expected to be elicited with greater amplitude for the ERPs of hit responses that were given high level of JOL.

Considering the behavioral data, it is hypothesized that the reaction time will decrease as the level of JOL increases. The other hypothesis for behavioral data is that correct recognition rate will increase as JOL level increases.

This thesis is a part of TÜBİTAK project (No: 120K914; Irak, 2023).

Chapter 2

Method

2.1 Participants

This study was carried out with seventy-two young adults (49 female, 23 male) aged between 18-27 ($M=21.64$; $S.D.= 2.09$). The participants were either undergraduate or graduate students or alumni. All were right-handed native Turkish speakers with normal or corrected-to-normal vision. None of them had any psychiatric or neurological conditions. Mini International Neuropsychiatric Interview (MINI) was used to screen them for psychiatric conditions. Neurological screening, on the other hand, was conducted with a checklist that included questions about concentration difficulties, memory problems, physical or mental fatigue, and history of trauma such as head and neck injury. Additionally, those who take medications that may affect central nervous system, or those who have taken such medications for an extended period and have recently stopped, did not included in the study.

This study was conducted under COVID-19 pandemic conditions. Before the data collection process started, it was decided not to include COVID-19 survivors in the study since the short and long-term effects of the COVID-19 disease caused by the SARS-CoV-2 virus on cognitive processes have not been clarified yet. However, since the rate of transmission in the community has reached a high level in the ongoing process, and it has become challenging to find new participants, instead of the criteria that the participants have never had COVID-19, the criteria that the transmission has not occurred within the last three months, even if they have had COVID-19, and that the treatment must have been done on an outpatient basis were sought.

For those who were identified eligible after the screenings, appointments made for participation. The experiments arranged to start either at 10.00 a.m. or at 2.00 p.m. The participants informed that they should sleep well the night before the experiment, not use alcohol or any illicit drugs, not be hungry, and stop caffeine-containing food intake at least three hours before the experiment.

The experiment was announced by posting a flier in the faculty buildings and on the online platforms of Bahçeşehir University. All participants gave informed consent and received either a gift voucher (50 Turkish Lira) or course credit for

compensation. The study is approved by the Bahçeşehir University Scientific Research and Publication Ethics Committee and funded by the Scientific and Technological Research Council of Turkey (TÜBİTAK) (Project number: 120K914).

2.2 Materials

2.2.1 Mini international neuropsychiatric interview (MINI). MINI offers a quick and easy screening opportunity. It is organized into diagnostic modules, and assesses mood disorders, psychotic disorders, alcohol-substance use disorders, anxiety disorders, obsessive-compulsive and related disorders, eating disorders, trauma and stressor-related disorders, and antisocial personality disorder (Sheehan et al., 1998). It was shown to be highly valid and reliable when compared to the Structured Clinical Interview for DSM-IV (SCID-I) form. Turkish Adaptation 5.0.0 study of MINI, which was conducted by Engeler (2004), was used in this study.

2.2.2 Experimental task. A list of word-pairs was used in the study for which 188 words consisting of five or six letters with high frequency selected from a word-frequency database in Turkish (Göz, 2003). These selected words then randomly made up to obtain a study list containing 94 word pairs. The first and last two of these word pairs were not included in the analyses to eliminate the primacy and recency effects. Therefore, all the statistical analyses made over 90 word pairs.

The experimental task (see Figure 1) consisted of five phases: presentation (1), JOL (2), FOK (3), Re-FOK (4) and recognition (5). In the presentation (learning) phase, the participants were instructed that pairs of words will be shown on the screen that they need to learn since they will be asked questions about these words in the subsequent phases. No specific instruction is given, except they are expected to learn at their best. Each pair of words appeared in the middle of the screen for 3 s consecutively, and the presentation time between word pairs was 1 s.

In the JOL phase, after the presentation phase was completed, the cue of each word pair was shown on the screen, and the participants were asked to indicate whether they remembered the target word. The stimuli included at this phase were completely the same as the presentation phase, but the order of the presentation was different and randomly organized. Each of the cue words was shown on the screen for 3 s. Then, after a black screen that remained for 1 s, a screen with three options appeared. Participants provided their JOL responses by clicking one of those three options with

the mouse that appeared on the screen for 3 s: “Definitely able to remember”, “Uncertain” or “Definitely not able to remember”.

In the FOK phase, participants were presented with the words they saw in the first stage, and 45 new words (only as cue words), each remaining on the screen for 3 s. They were asked to indicate their decision on whether they would recognize the target of the cue word on the screen if it presented with the options in the future by choosing one of the “Yes”, “Feeling of Knowing” or “No” choices within 3 s. 1 s after the decision was made, they were asked to report their level of confidence by choosing one of the “Sure”, “Uncertain” or “Not sure” choices within 3 s. In the Re-FOK phase, participants were asked to make re-decision and re-confidence evaluations to the same stimuli as in the previous stage. In the Re-FOK phase, participants were asked to make re-decision and re-confidence evaluations to the same stimuli as in the previous stage.

The last phase consisted of a recognition test. The cue word of each pair that was presented in the first phase was shown again, but this time with the four choices to choose the target among them. Participants had to provide their responses in 4 s by clicking one of those four choices with the mouse. One of these choices was the target word, and the other three were distractors. One of the distractors was chosen from another word in the studied list, and the other two were not in the studied list. The order and the matching of word pairs and distractors were done randomly. There was 1 s black screen between each multiple-choice screen. All the paradigm was prepared using the C-Sharp programming language. The words appeared on the screen in white on a black background with a 40-point Arial font.

The flow of the experiment is shown in Figure 1. It is important to note that this study focuses on the first (presentation), second (JOL), and final (recognition) phases only.

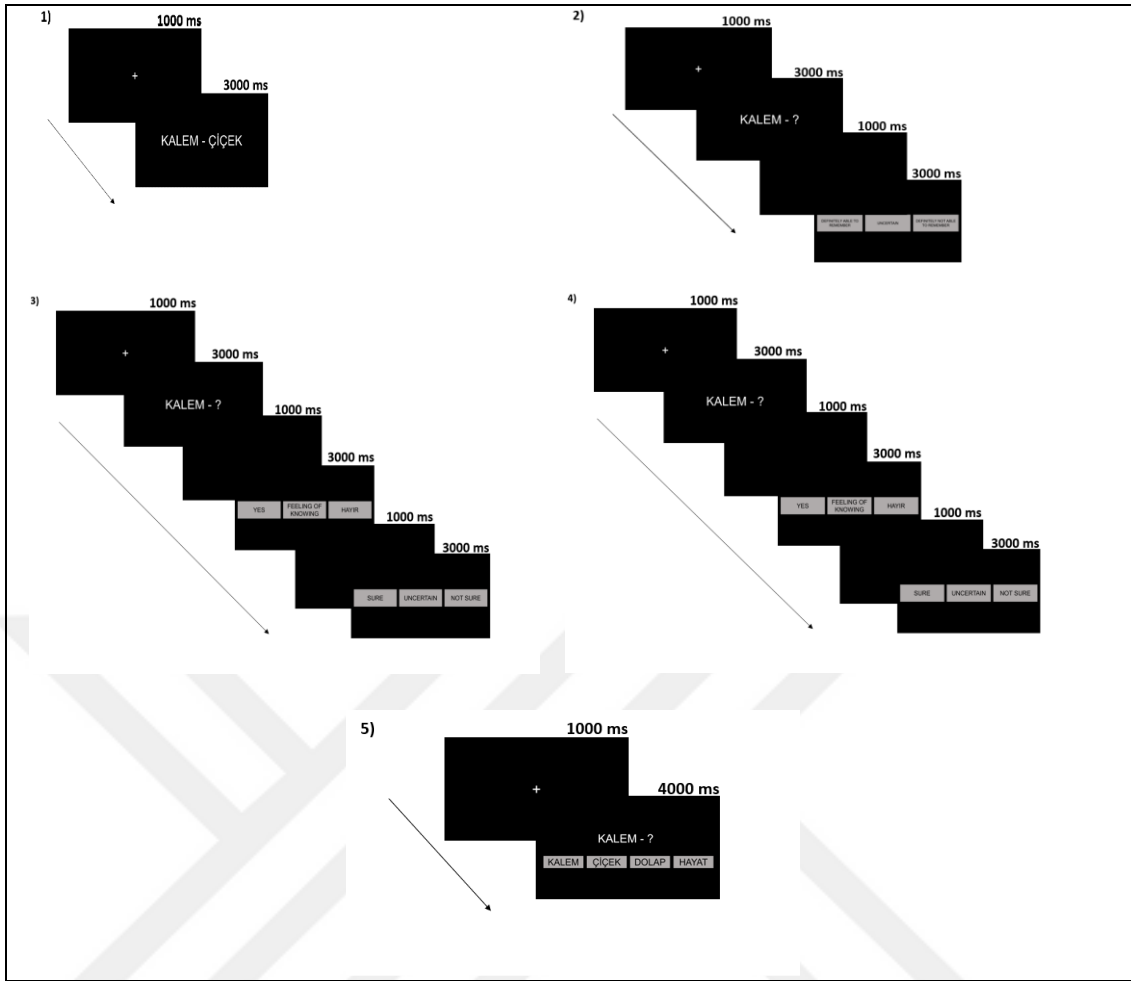


Figure 1. The flow of the experimental task.

2.3 EEG Recording

The experiments were carried out in a Faraday cage isolated from sound and electric fields. Participants were seated in a chair in front of a computer with 29-inch screen. Recording, storage and analysis were performed using 64-channel EEG-EP systems, Curry 8.12 and NeuroScan 4.51.

EEG activity recorded by using 64 Ag-Ag/Cl electrodes mounted in elastic Quickcaps (Neuromedical Supplies, Compumedics, Inc., Charlotte). EOG (Electrooculography) signals were recorded with additional electrodes placed below and above the left eye (for vertical eye movements), and the outer canthus of each eye (for horizontal eye movements). EEG signals were recorded from 62 electrodes (FP1, FPZ, FP2, AF3, AF4, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FT8, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, T7, T8, C5, C3, C1, CZ, C2, C4, C6, TP7, TP8, CP5, CP3, CP1, CPz, CP2, CP4, CP6, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4,

PO6, PO8, CB1, CB2, O1, O2, Oz) arranged according to the standard 10–20 system, with two additional electrodes placed on the left and right mastoids (M1/M2), All EEG electrodes referenced on-line to the reference electrode at vertex and re-referenced off-line to linked mastoids. EEG signals were amplified and recorded at a 1000 Hz sampling rate with high- and low-pass filter set at 0.15 and 100 Hz, respectively. EEG electrode impedance kept below 5 k Ω .

The collected continuous data were filtered between 0.15-30 Hz with Curry 8.12 program. Thus, high-frequency blocks in the data caused by noise sources such as muscular movements or high voltage changes are eliminated. Then, artefact reduction was performed for the signal patterns of vertical and horizontal eye movements in the EEG and EOG channels using the Neuroscan 4.51 program on these filtered data. However, in some cases there were still noisy images on the remaining data. In such cases, the data were treated with the same artefact reduction method.

2.4 Statistical Analyses

EEG recordings analyzed in the temporal domain in which segments were extracted with an interval of 100 ms preceding and 1000 ms following the stimulus onset. ERPs for three distinct levels in the JOL phase (“Definitely able to remember” (1), “Uncertain” (2) or “Definitely not able to remember” (3)) averaged. Additionally, ERPs for correct recognitions in the final phase also averaged according to their JOL levels assigned in the second phase.

In the JOL phase, statistical analyses for ERPs were performed for the frontal, fronto-central, central and parietal sites. However, for the recognition phase, analyses were performed for frontal, fronto-central, central, parietal and parieto-occipital sites. In order to clearly see the hemispheric features of the possible differences in the responses, three electrodes (left, middle, right) from each site were focused. Thus, following electrodes were included the analyses: Fz, F1, F2, FCz, FC1, FC2, Cz, C1, C2, Pz, P1, P2, POz, PO3, PO4.

Statistical analysis of the ERPs for JOL responses performed with 3x3 repeated measures ANOVA since there are two separate within-subjects factors (JOL responses: “Definitely able to remember”, “Uncertain”, “Definitely not able to remember”, and hemisphere: left, midline, right). ERPs for the recognition phase were also statistically analyzed again with 3x3 repeated measures ANOVA. Besides, analyses of behavioral

data performed over the accuracy and reaction time. The accuracy was analyzed with one-way repeated measures ANOVA for correctly recognized and incorrectly recognized distinct JOL levels separately. The reaction time of these responses were also compared with the one-way repeated-measures ANOVA.



Chapter 3

Results

3.1 Behavioral Results

Three distinct levels in the JOL phase (“Definitely able to remember”, “Uncertain”, “Definitely not able to remember”) and the reaction times (RT) for these responses were analyzed using repeated-measures analysis of variance (ANOVA). The Greenhouse–Geisser correction (Greenhouse & Geisser, 1959) was applied for each analysis whenever the sphericity assumption was violated. Bonferroni test was used for significance analyses between means.

Participants responded to 90 stimuli as “Definitely able to remember” with 28.52% ($M = 25.67$, $SE = 1.70$), “Uncertain” with 27.19% ($M = 24.47$, $SE = 1.41$), and “Definitely not able to remember” with 42.61% ($M = 38.35$, $SE = 2.00$), while missed (not provided any response to) 1.68% of them ($M = 1.51$, $SE = .22$) (See Figure 2). One-way repeated-measures ANOVA revealed that there was a significant difference between response types ($F(1.73, 123.02) = 13.32$, $\eta p^2 = .158$, $p = .000$); the mean number of “Definitely not able to remember” responses was greater than the “Uncertain” and “Definitely able to remember” responses ($p \leq .001$).

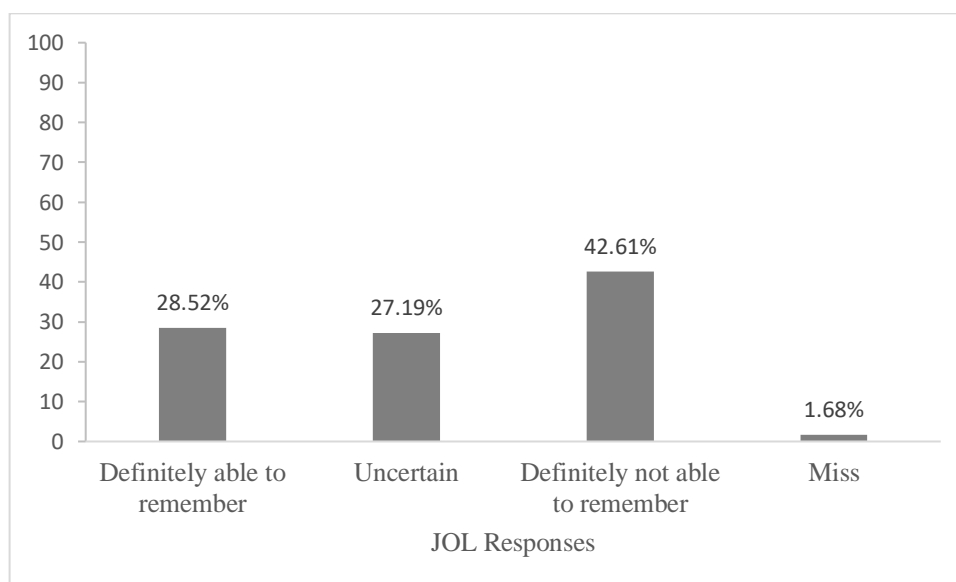


Figure 2. Percentage values of three distinct JOL levels

Analysis performed for the RTs of responses also revealed that there were significant differences among the levels ($F(1.57, 111.26) = 16.22$, $\eta p^2 = .186$, $p = .000$);

the mean RTs of “Definitely able to remember” response ($M = 1053.86$, $SE = 25.55$) was found to be shorter than the mean RTs of “Uncertain” ($M = 1209.75$, $SE = 37.25$) and “Definitely not able to remember” ($M = 1133.48$, $SE = 27.52$) responses ($p \leq .000$). Moreover, it was found that the mean RTs of “Uncertain” responses was longer than the mean RTs of “Definitely not able to remember” response ($p = .028$).

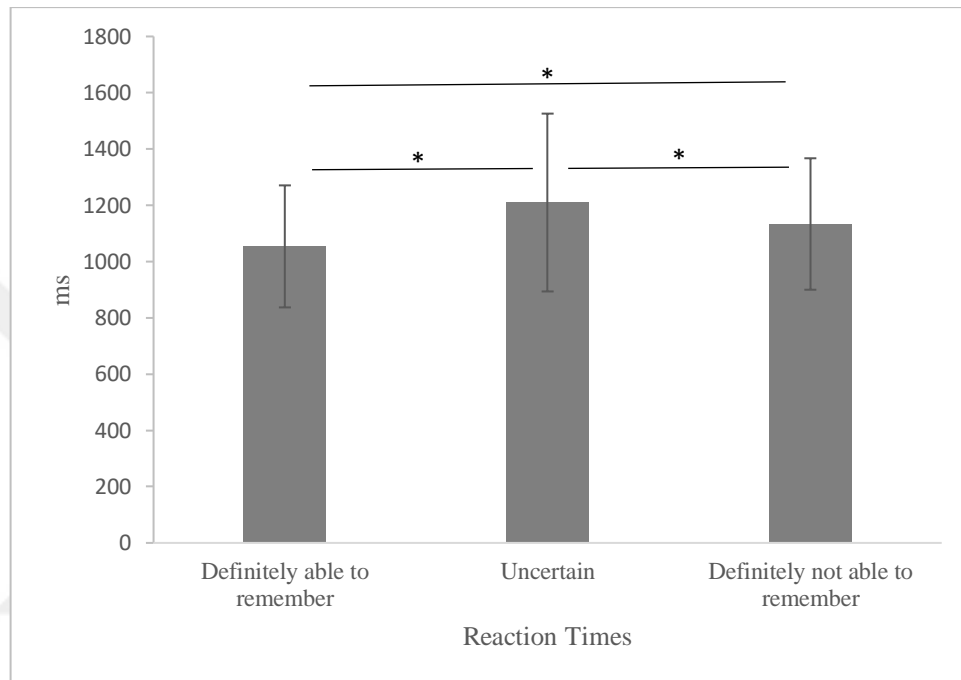


Figure 3. The mean reaction times of three distinct JOL levels

In addition, it was examined how the stimuli assigned distinct JOL levels were recognized in the subsequent memory test (correct vs incorrect). It was observed that there was a significant difference in terms of hit responses of the three distinct JOL levels in the recognition test ($F(1.75, 124.06) = 19.43$, $np^2 = .215$, $p = .000$). The mean number of “Definitely able to remember” responses that were correctly recognized in the memory test ($M = 20.51$, $SE = 1.61$) was found to be greater compared to the mean number of “Uncertain” ($M = 11.17$, $SE = .79$) and “Definitely not able to remember” ($M = 12.72$, $SE = .78$) responses that were correctly recognized in the memory test ($p \leq .000$).

Furthermore, a significant difference was also found between the incorrect recognition number of the three distinct JOL levels ($F(1.40, 99.15) = 51.79$, $np^2 = .422$,

$p = .000$). The mean number of “Definitely not able to remember” and “Uncertain” responses that were incorrectly recognized in the memory test ($M = 17.25$, $SE = 1.44$; $M = 9.13$, $SE = .89$, respectively.) were found to be greater than the mean number of “Definitely able to remember” responses that were incorrectly recognized in the memory test ($M = 3.47$, $SE = .53$) ($p \leq .000$). Additionally, it was found that the mean number of “Definitely not able to remember” responses that were incorrectly recognized in the memory test was greater than the mean number of “Uncertain” responses that were incorrectly recognized in the memory test ($p = .000$).

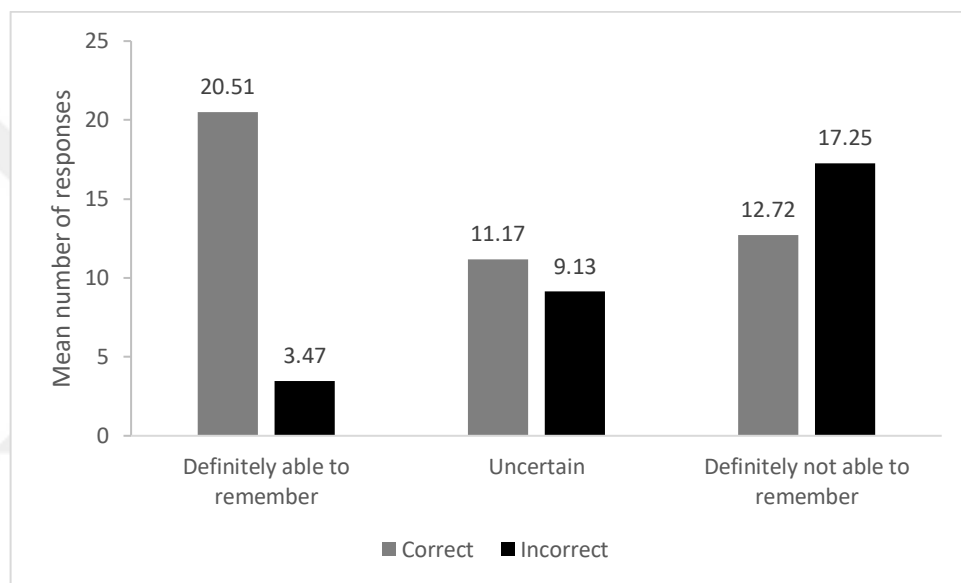


Figure 4. The mean correct and incorrect recognition of JOL responses.

3.2 ERP Results

3.2.1 Visual analysis. The grand average of the stimulus-locked ERPs obtained from the JOL phase was calculated for the distinct JOL levels. The grand average topography obtained for this condition can be seen in Appendix 1. Four sites and 12 channels, namely frontal (Fz, F1, F2), fronto-central (FCz, FC1, FC2), central (Cz, C1, C2), and parietal (Pz, P1, P2), were inspected for this condition. The following ERP components were detected in the frontal, fronto-central, central sites: N100 (80-120 ms), P200 (140-195 ms), N200 (235-310 ms), P300 (280-400 ms). Additionally, a negative component in the middle time window (330-500 ms) was also detected in central site. Moreover, in parietal site P100 (95-145 ms), N100 (145-185 ms), P200

(190-230 ms), N200 (230-270 ms), P300 (270-400 ms), and a negative component in the middle time window (330-500 ms) were detected. The comparison of these responses within themselves was carried out with further statistical analyses.

The grand average of the stimulus-locked ERPs obtained from the recognition phase was also calculated. ERPs at this phase were calculated only for hit responses, and they were separated according to the JOL levels assigned to them in the previous phase. Therefore, there were three types of responses namely, “Definitely able to remember-hits”, “Uncertain-hits”, “Definitely not able to remember-hits”. These responses then compared within themselves in terms of FN400 and parietal old/new effect amplitudes. The grand average topography for this condition can be seen in Appendix 2. Five sites and 15 channels, namely frontal (Fz, F1, F2), fronto-central (FCz, FC1, FC2), central (Cz, C1, C2), parietal (Pz, P1, P2), and parieto-occipital (POz, PO3, PO4), were inspected. A negative slow wave in the frontal, fronto-central and central sites with the latency of 350-600 ms, and a positive slow wave in the parietal and parieto-occipital sites with the latency of 450-700 ms were detected. The comparison of these responses within themselves was carried out with further statistical analyses.

3.2.2 Statistical analysis. For the repeated-measures ANOVAs, we adhered to the same procedures as those employed in the behavioral analyses. Furthermore, paired sample t-test was conducted for post hoc analysis when interaction effect was found statistically significant.

3.2.2.1 Comparison of the ERPs elicited for the distinct JOL levels. Peak amplitude values were used for the N100, P100, P200, N200, and P300 whereas mean amplitude values were used for the negative component with 330-500 ms latency. The findings are presented separately for each component below. For the topography of these 12 channels see Figure 5. Results were summarized in Table 1.

3.2.2.1.1 N100 amplitude. Results showed that the main effects of both hemisphere and response were statistically significant in the fronto-central site. N100 was found to be elicited with greater amplitude in the midline ($M = -2.41$, $SE = .170$) than in the left and right hemispheres ($M = -2.12$, $SE = .150$; $M = -2.25$, $SE = .164$, respectively) in this site ($p \leq .009$). Moreover, it was found that “Definitely able to remember” responses ($M = -2.52$, $SE = .193$) elicited N100 with greater amplitude

compared to “Definitely not able to remember” responses ($M = -1.89$, $SE = .152$) ($p = .000$).

The main effect of response was also statistically significant in the central site. “Definitely able to remember” responses ($M = -2.33$, $SE = .170$) elicited N100 with greater amplitude compared to “Definitely not able to remember” responses ($M = -1.77$, $SE = .130$) ($p = .000$). No more statistically significant results were found in terms of N100 amplitude among distinct JOL levels.

3.2.2.1.2 P100 amplitude. No statistically significant result was found among distinct JOL levels in terms of P100 amplitude.

3.2.2.1.3 P200 amplitude. Results showed that the main effect of hemisphere was statistically significant in the frontal and fronto-central sites. P200 was found to be elicited with greater amplitude in the midline ($M = 2.66$, $SE = .198$) than in the left hemisphere ($M = 2.41$, $SE = .185$) in the frontal site ($p = .000$). In fronto-central site, it was found to be elicited with greater amplitude in the midline ($M = 3.07$, $SE = .214$) than in the left and right hemispheres ($M = 2.62$, $SE = .205$; $M = 2.77$, $SE = .199$, respectively) ($p \leq .000$). No more statistically significant results were found in terms of P200 amplitude among distinct JOL levels.

3.2.2.1.4 N200 amplitude. Results showed that the main effect of hemisphere was statistically significant in the frontal, fronto-central, and parietal sites. In all these three sites, N200 was found to be elicited with greater amplitude in the midline ($M = -1.99$, $SE = .191$; $M = -2.35$, $SE = .193$; $M = -2.20$, $SE = .255$, respectively) than in the right hemisphere ($M = -1.76$, $SE = .160$; $M = -2.04$, $SE = .171$; $M = -1.59$, $SE = .210$, respectively) ($p \leq .023$). No more statistically significant results were found in terms of N200 amplitude among distinct JOL levels.

3.2.2.1.5 P300 amplitude. Results showed that the main effect of hemisphere was statistically significant in the fronto-central and parietal sites. P300 was found to be elicited with greater amplitude in the midline ($M = 1.98$, $SE = .164$) than in the left hemisphere ($M = 1.72$, $SE = .158$) in the fronto-central site ($p = .027$). In parietal site, it was found to be elicited with smaller amplitude in the left hemisphere ($M = 1.70$, $SE = .127$) compared to the midline and the right hemisphere ($M = 2.05$, $SE = .149$; $M = 2.30$, $SE = .157$, respectively) ($p \leq .001$). Moreover, it was found to be elicited with a smaller amplitude in the midline compared to the right hemisphere ($p = .014$). No more

statistically significant results were found in terms of P300 amplitude among distinct JOL levels.

3.2.2.1.6 *Negative component with 330-500 ms latency.* No statistically significant result was found among distinct JOL levels in terms of the amplitude of this component.

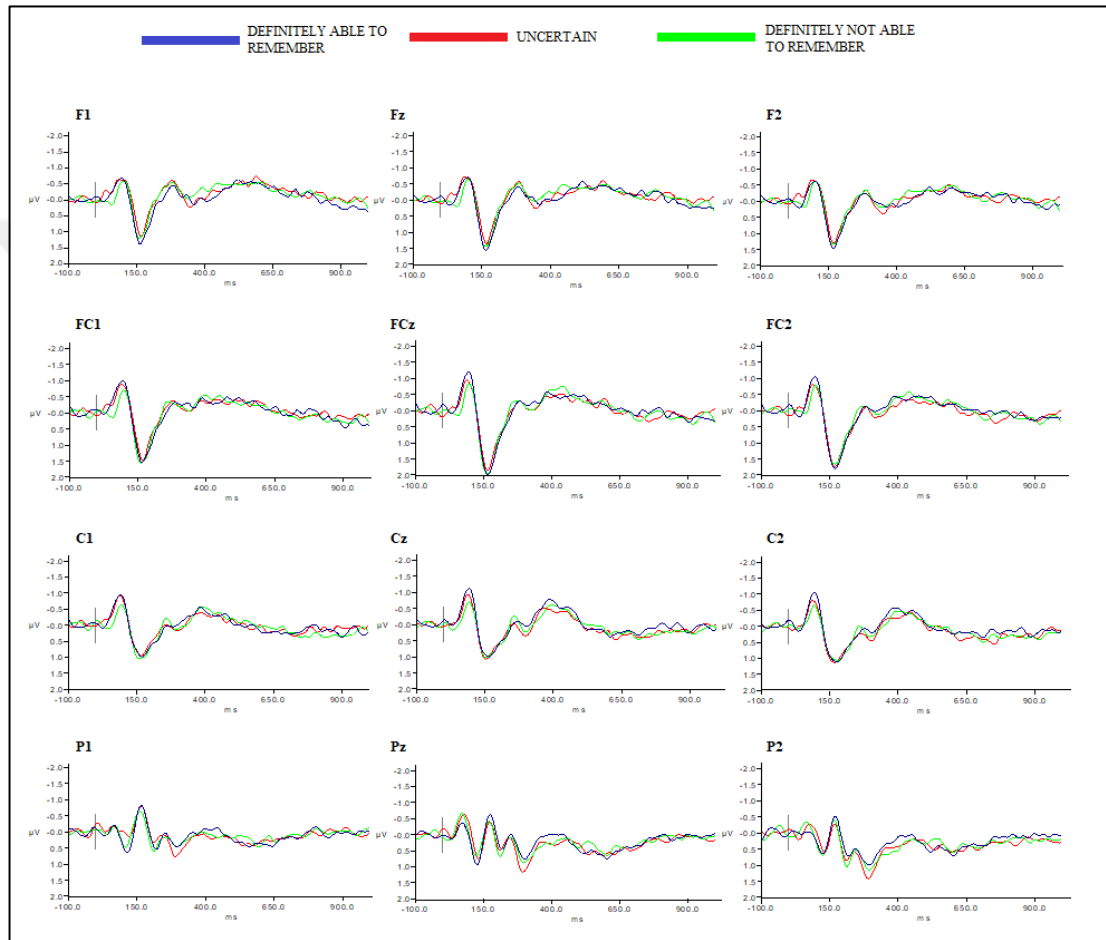


Figure 5. ERP grand average waveforms of distinct JOL levels in frontal, fronto-central, central, and parietal sites (from top to bottom).

Table 1

Effects of distinct JOL levels and hemispheres on ERP components at different electrode sites: 3x3 repeated-measures ANOVA results with post-hoc comparisons.

ERP Component	Effect	Site			
		Frontal	Fronto-central	Central	Parietal
P100	Hemisphere (H)				Ns
	Response (R)				Ns
	H x R				Ns
N100	Hemisphere (H)	Ns	$F(1.32, 61.91) = 5.80, \eta^2 = .110 **$	Ns	Ns
	Response (R)	Ns	$F(2, 94) = 7.17, \eta^2 = .132 **$	$F(2, 98) = 8.84, \eta^2 = .153 **$	Ns
	H x R	Ns	Ns	Ns	Ns
P200	Hemisphere (H)	$F(1.56, 71.90) = 6.77, \eta^2 = .129 **$	$F(1.69, 92.93) = 20.29, \eta^2 = .269 **$	Ns	Ns
	Response (R)	Ns	Ns	Ns	Ns
	H x R	Ns	Ns	Ns	Ns

Table 1 (cont'd)

		Frontal	Fronto-central	Central	Parietal
N200	Hemisphere (H)	$F(1.56, 52.92) = 3.57$, $\eta^2 = .095$ *	$F(1.41, 42.25) = 3.73$, $\eta^2 = .111$ *	Ns	$F(2, 30) = 5.51$, $\eta^2 = .269$ **
	Response (R)	Ns	Ns	Ns	Ns
	H x R	Ns	Ns	Ns	Ns
P300	Hemisphere (H)	Ns	$F(2, 60) = 4.43$, $\eta^2 = .129$ *	Ns	$F(1.57, 80.20) = 18.34$, $\eta^2 = .264$ **
	Response (R)	Ns	Ns	Ns	Ns
	H x R	Ns	Ns	Ns	Ns
NC	Hemisphere (H)			Ns	Ns
	Response (R)			Ns	Ns
	H x R			Ns	Ns

Note. * indicates significant results at .05 level (two-tailed); ** indicates significant results at the .01 level (two-tailed).

Ns= non-significant. NC= Negative component with 330-500 ms latency.

Blank cells in the table indicate that the component in that column is not identified on the relevant site.

3.2.2.2 Comparison of the ERPs elicited for the hit responses in the recognition phase. Peak amplitude values were used for the FN400 and parietal old/new effect. The findings are presented separately for each component below. For the topography of these 15 channels see Figure 6. Results were summarized in Table 2.

3.2.2.2.1 FN400 amplitude. Hit responses were compared within themselves according to the JOL levels assigned during the previous phase. Results showed that the main effect of hemisphere was statistically significant in the frontal, fronto-central and central sites; FN400 was found to be elicited with smaller amplitude in the left hemisphere ($M = -3.679$, $SE = .278$; $M = -3.980$, $SE = .286$; $M = -3.897$, $SE = .269$, respectively) than in the midline ($M = -4.409$, $SE = .312$; $M = -5.142$, $SE = .333$; $M = -4.573$, $SE = .322$, respectively) and in the right hemisphere ($M = -4.264$, $SE = .292$; $M = -4.655$, $SE = .314$; $M = -4.343$, $SE = .293$, respectively) ($p \leq .014$). Moreover, it was found to be elicited with greater amplitude in the midline compared to the right hemisphere in the fronto-central site ($p = .001$). However, no significant results were found regarding the main effect of the response or the interaction effect of the hemisphere and response ($p \geq .050$).

3.2.2.2.2 Parietal old/new effect amplitude. Hit responses were compared within themselves according to the JOL levels assigned to them during the previous phase. Results showed that the main effect of hemisphere was marginally significant in the parietal site ($p = .051$). However, no statistically significant difference was found between hemispheres in the Bonferroni comparisons ($p \geq .110$). The main effect of the hemisphere was also significant in the parieto-occipital site. This component was found to be elicited with greater amplitude in the right hemisphere ($M = 4.305$, $SE = .349$) than in the midline ($M = 3.175$, $SE = .268$) ($p = .001$).

Additionally, the interaction effect of the hemisphere and response was found to be significant in the parietal site. “Definitely not able to remember-hits” elicited smaller amplitude in the left hemisphere ($M = 2.723$, $SE = .372$) than in the midline and right hemisphere ($M = 3.532$, $SE = .397$; $M = 3.738$, $SE = .429$, respectively) ($p \leq .016$). Moreover, significant difference between responses in amplitude was found in the right hemisphere. “Definitely able to remember-hits” ($M = 2.654$, $SE = .325$) elicited parietal old/new effect with smaller amplitude compared to “Uncertain-hits” and “Definitely

not able to remember-hits” ($M= 3.472, SE= .368; M= 3.738, SE= .429$, respectively) ($p \leq .035$).

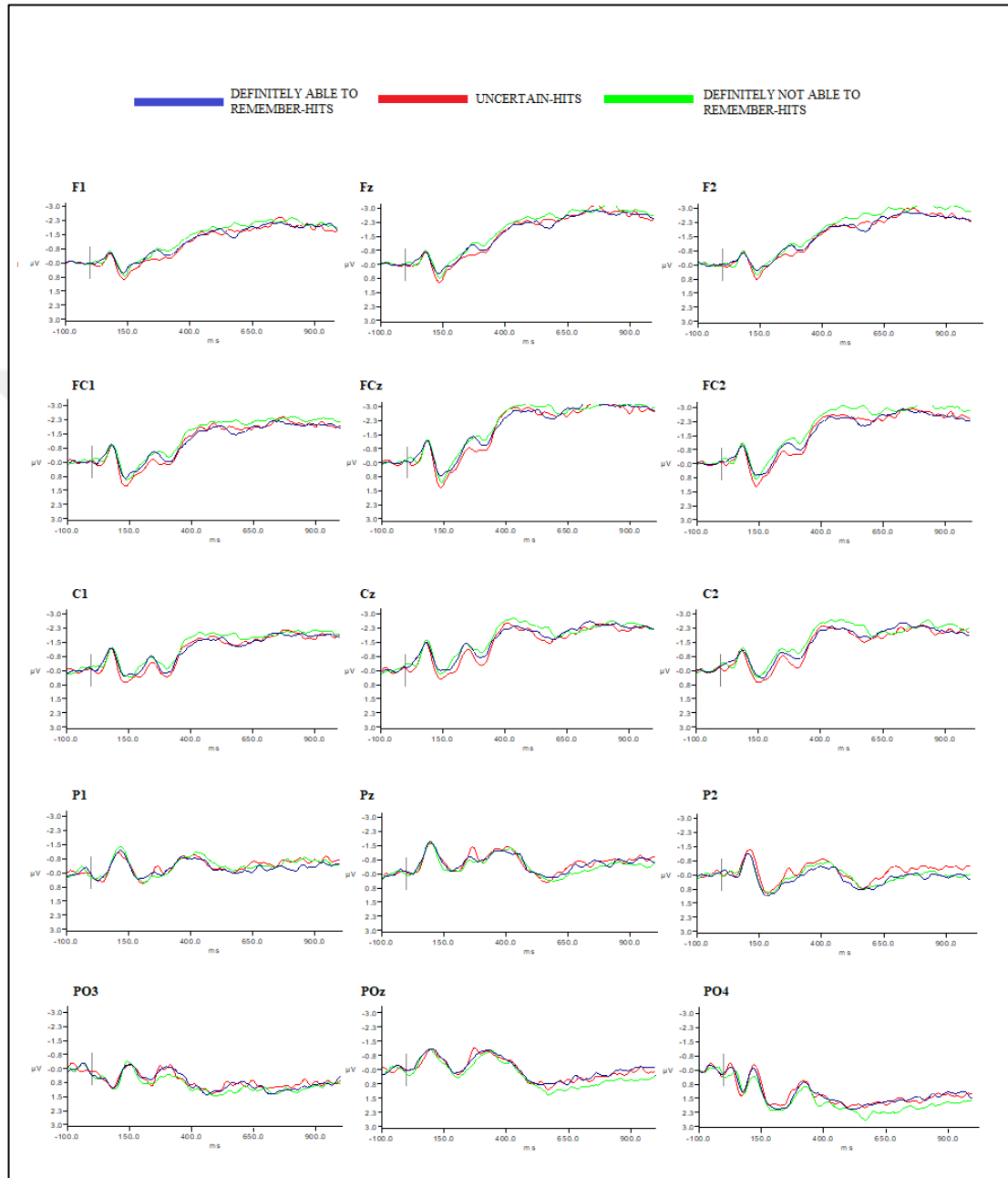


Figure 6. ERP grand average waveforms for the hit responses during the recognition phase separated according to the JOL levels assigned during the previous phase in frontal, frontocentral, central, parietal, and parieto-occipital sites (from top to bottom).

Table 2

Effects of distinct hit responses and hemispheres on ERP components at different electrode sites: 3x3 repeated-measures ANOVA results with post-hoc comparisons.

Site	Effect	ERP Component	
		FN400	Parietal Old/New Effect
Frontal	Hemisphere (H)	$F(2, 116) = 19.74, \eta^2 = .254^{**}$	
	Response (R)	Ns	
	H x R	Ns	
Fronto-central	Hemisphere (H)	$F(1.80, 104.42) = 37.71, \eta^2 = .394^{**}$	
	Response (R)	Ns	
	H x R	Ns	
Central	Hemisphere (H)	$F(1.81, 101.51) = 12.37, \eta^2 = .181^{**}$	
	Response (R)	Ns	
	H x R	Ns	
Parietal	Hemisphere (H)		Ns
	Response (R)		Ns
	H x R		$F(2.98, 86.54) = 2.87, \eta^2 = .090^*$
Parieto-occipital	Hemisphere (H)		$F(1.51, 66.42) = 6.44, \eta^2 = 0.126^{**}$
	Response (R)		Ns
	H x R		Ns

Note. * indicates significant results at .05 level (two-tailed); ** indicates significant results at the .01 level (two-tailed).

Ns= non-significant. Blank cells in the table indicate that the component in that column is not identified on the relevant site.

Chapter 4

Discussion

4.1 Overview

It is aimed to investigate the neural correlates of JOL with ERP methodology in the present study. The ERPs elicited for the distinct JOL levels are compared. ERP analyses were performed over the frontal, fronto-central, central and parietal sites, with three channels from each site (left hemisphere, midline, right hemisphere). N100, P200, N200, P300 components were detected in frontal, fronto-central and central site channels. In the central site, a negative component in the middle time window (330-500 ms) was also detected. In the parietal site, P100, N100, P200, N200, P300, and a negative component in the middle time window (330-500 ms) were detected.

Additionally, ERPs elicited for the hit responses in the recognition phase were also compared within themselves according to the JOL levels assigned to them. The comparison made over the amplitude of mid-frontal old/new effect (FN400) and parietal old/new effect. ERP analyses were performed over the frontal, fronto-central, central, parietal and parieto-occipital sites, with three channels from each site (left hemisphere, midline, right hemisphere). FN400 was observed over the frontal, fronto-central and central channels with 350-600 ms latency, while parietal old/new effect was observed over the parietal and parieto-occipital channels with 450-700 ms latency.

The general results of the ERP analyses supported the hypothesis that distinct JOL levels elicit familiarity-related ERP-components (P100, N100, P200, N200, P300) in the early time window (within 200-300 ms), and only the N100 component did vary in amplitude among distinct JOL levels. It was also observed, as hypothesized, that a negative slow wave (330-500 ms) elicited for distinct JOL levels. However, we expected that component to be elicited with greater amplitude for high level of JOL than the other levels, but this was not the case. No significant difference was found in terms of the amplitude of this component among distinct JOL levels. Moreover, ERP analyses in the recognition phase showed that FN400 did not vary in amplitude among distinct hit responses. Contrary to our hypothesis, the parietal old/new effect is elicited with smaller amplitude by “Definitely able to remember-hits” than the other two hit response types.

The behavioral results, on the other hand, revealed that during the JOL phase, participants showed a tendency to choose “Definitely not able to remember” (42.61%) for the target words, while selecting “Uncertain” (27.19%) and “Definitely able to remember” (28.52%) less frequently. Furthermore, RTs for these responses also varied, with “Definitely able to remember” responses being provided in the shortest amount of time, followed by “Definitely not able to remember” and “Uncertain” responses, respectively.

Additionally, JOL responses were compared according to the recognition performance. In terms of correct recognition, the mean number of “Definitely able to remember” responses were found to be higher than the other two response types. In terms of incorrect recognition, the mean number of “Definitely not able to remember” responses were found to be higher than the other two response types. These findings are consistent with the hypotheses of the present study.

4.2 Discussion for Behavioral Results

During the JOL phase, the participants predominantly chose the “Definitely not able to remember” response, accounting for 42.6% of the responses. Their pronounced inclination towards this response is worthwhile because they made assessments in a delayed JOL condition. Previous studies have demonstrated that individuals could rely more on heuristics when making assessments under immediate JOL conditions which may not be highly indicative of actual memory performance. For instance, when encoding fluency (Kornell et al., 2011), semantic relatedness (Dunlosky & Matvey, 2001; Matvey et al., 2006; Undorf & Erdfelder, 2015), or identity (Castel, McCabe, & Roediger, 2007) is high, it can lead to a kind of illusion that cause an overestimation regarding the predictions about future memory performance. Furthermore, individuals may also be more influenced by unrealistic beliefs and evaluations concerning memory processes in the immediate JOL condition (Frank & Kuhlmann, 2017; Mueller et al., 2014) which can also lead to overestimated predictions about the memory performance. However, it has been reported that the influence of such illusions diminishes in the delayed JOL condition, and individuals make more accurate evaluations (Metcalf & Dunlosky, 2008; Luna et al., 2018). The finding that participants more frequently chose the “Definitely not able to remember” therefore indicates that they made more realistic assessments.

Secondly, it was found that RT for the “Definitely able to remember” responses was shorter compared to the other two JOL levels. Additionally, RT for the “Uncertain” responses was longer than the “Definitely not able to remember” responses. These findings are consistent with the two-factor hypothesis proposed regarding JOL (Benjamin, 2005). According to this hypothesis, when individuals have limited time, in the delayed JOL condition, they primarily go through the available cues and if these cues are sufficient to engage in a retrieval attempt, they do. The successfully retrieved items are assessed with a high-level JOL (in this study, “Definitely able to remember”) and the response time will be shorter for those items, negatively correlating with fluency of retrieval (Benjamin & Bjork, 1996). The unretrieved items, on the other hand, will be assessed with a low-level JOL (in this study, “Definitely not able to remember”). Therefore, it can be interpreted as follows: the participant may have continued searching for a while but failed to retrieve the item and discontinued the search when they provided “Definitely not able to remember” response. However, when participants provided “Uncertain” response, they may still be continuing the search since they may believe they know the target word, so that the longest RT was observed in this condition.

Thirdly, the finding that participants had a higher proportion of correct recognitions among the items they responded to as “Definitely able to remember” carries significance in accuracy. Similarly, there was higher proportion of incorrect recognitions among the items they responded as “Definitely not able to remember” compared to “Uncertain” and “Definitely able to remember” responses. Also, incorrect recognition rate was higher among the items they responded as “Uncertain” compared to “Definitely able to remember”. This pattern suggests that individuals are good estimators in their memory performance. As mentioned earlier, since the study was conducted in the delayed JOL condition, these results are consistent with the hypotheses.

As the findings of behavioral analyses are inspected cumulatively, it appears that the hypotheses proposed for the delayed JOL phenomenon are supported. The dual memories hypothesis, for instance, suggest that individuals in the delayed JOL condition make estimations based on the availability of retrievable information when making JOL (Nelson & Dunlosky, 1991). In other words, individuals make these assessments via an implicit or explicit retrieval experience, which also aligns with the

self-fulfilling proficiency hypothesis. The self-fulfilling hypothesis states that individuals make assessments in the delayed JOL condition based on whether the target information is retrieved or not, and this will correspond to the memory performance (Spellman & Bjork, 1992). This is also consistent with Koriat's (2012) self-consistency model. According to this model, individuals' subjective confidence regarding their memory is, in fact, an assessment of the likelihood of being able to make the same evaluation in the future again. Although confidence may appear to be a retrospective metacognitive evaluation, according to the approach proposed by this model, it is actually prospective. Therefore, in the present study, if individuals in the delayed JOL condition make a prospective assessment based on an explicit or implicit retrieval experience and report a JOL level accordingly, they may have also rated the likelihood of it happening in the future. Indeed, this is supported by their good resolution in predicting memory performance which is also in line with the view that past retrieval experiences serve as predictors for future retrieval (Tulving, 1964).

However, despite the apparent support for these hypotheses, the results indicate that the participants are not perfect in their future estimates. For instance, the mean number of the items responded as "Definitely able to remember" that were incorrectly recognized was 3,5, while the mean number of the items responded as "Definitely not able to remember" that were correctly recognized was 12,7. These findings suggest that participants' sole criterion for making JOLs was not retrieval success, and other factors may introduce noise into the assessment process. Previous studies comparing JOLs with confidence ratings in terms of accuracy have referred to a relationship of "JOL = confidence + variation" where the variation factor was reported to be inferential errors (Dougherty et al., 2005; Putnam et al., 2022). The imperfect performance of the participants in the present study might be due to those inferential errors.

In sum, the hypotheses related to behavioral data have been largely confirmed. As the level of JOL increased, the correct recognition rate in the subsequent memory test also increased. The shortest RT is observed in the condition where high-level JOL responses ("Definitely able to remember") are given. However, contrary to the hypothesis, the longest RT is observed in the condition where "Uncertain" responses are given, for which the interpretation is made above.

4.3 Discussion for ERP Results

In the JOL phase, the N100, P200, N200, and P300 components were detected for the distinct levels at frontal, fronto-central, and central sites. At the parietal site, the P100, N100, P200, N200, and P300 components were detected. Moreover, a negative component was detected in the middle time window at central and parietal sites.

In the recognition phase, the focus was solely on hit responses, which were analyzed by separating them based on the JOL levels assigned in the previous phase. The aim was to examine the FN400 and parietal old/new effect. The amplitudes of these two effects were compared across the following conditions: “Definitely able to remember-hits”, “Uncertain-hits” and “Definitely not able to remember-hits”. The findings revealed a negative slow wave at frontal, fronto-central, and central sites, while a positive slow wave was observed at parietal and parieto-occipital sites. These responses were identified as the FN400 and parietal old/new effect, respectively.

The ERP comparisons for both the JOL phase and the recognition phase have been discussed below under separate headings.

4.3.1 Discussion of ERP results in the JOL phase. As hypothesized, early stimulus-locked ERP components (within 200-300 ms), which indicates that the JOL is observable within that time window, were elicited for distinct JOL levels. Consistent with the hypothesis, a negative component was also elicited for all levels after 300 ms. However, it was hypothesized that the early time window responses would not show a significant difference in amplitude among distinct JOL levels, while the magnitude of the later response would be greater for high-level JOL. The results partially confirm the former since it was found that the amplitude of the N100 component among distinct JOL levels was differentiated. However, the latter hypothesis was not confirmed as the results indicate no significant difference in amplitude of the negative component among distinct JOL levels.

In this study, N100 was observed with a latency of 80-120 ms at frontal, fronto-central, central sites, and with a latency of 145-185 ms at parietal sites. It was elicited with a greater amplitude in the midline compared to the left and right hemispheres at the fronto-central site. Additionally, at the fronto-central and central sites, “Definitely able to remember” responses elicited N100 with greater amplitude compared to “Definitely not able to remember” responses.

The N100 component is associated with sensory-level processing rather than psychological or conscious processing (Hillyard, 1985). This component can be observed during the processing of stimuli in auditory (Hyde, 1997), visual (Foxye & Simpson, 2002), olfactory (Pause et al., 1996), somatosensory (Wang et al., 2008) modalities. N100 is a component that indexes attentional processes related to distinguishing relevant stimuli from irrelevant ones, and its amplitude is positively correlated with the level of engagement of attention in these processes (Mangun & Hillyard, 1987). It has also been suggested that N100 is a general cortical response rather than being a component with functional specificity or task sensitivity (Du et al., 2017). However, it has been argued that instead of simply being a response that emerges when attention is engaged, N100 is a response that indexes processes requiring attention for discrimination (Hillyard et al., 1998; Vogel & Stuck, 2000). In fact, it is a consistent finding in more complex paradigms that investigate the processes occurring after stimulus perception and selection that N100 forms a complex with the P200 component (Hyde, 1997). This observation suggests that N100 is not solely driven by exogenous factors, but rather reflects the involvement of endogenous processes as well. Indeed, it has been shown that increased N100 amplitude is associated with enhanced memory performance (Papageorgiou et al., 2009). Galfano et al. (2011) demonstrated while examining the neural correlates of retrieval-induced forgetting that practiced items elicited N100 with greater amplitudes compared to unpracticed items. Referring to the studies reporting the association of N100 with anticipatory processes (Vogel & Stuck, 2000), they suggested that this difference between practiced and unpracticed items might indicate an automatic process.

Our interpretation on the difference in N100 amplitude observed in favor of “Definitely able to remember” response in this study is as follows: During the learning phase of the experiment participants may have proficiently encoded many of the stimuli attracted this response, indicating a deep encoding process. It is a consistent finding that retrieval is influenced by the efficiency of encoding (Donchin, 1981; Luck & Kappenman, 2012). Therefore, when participants encountered these stimuli again during the JOL phase, selective attention might have engaged more strongly prior to higher level of processing, leading to the observed amplitude difference. Indeed, it has been reported that N100 may be associated with increased early selective attention (Gao et al., 2023). However, no ERP analysis to support this argument was conducted

during the learning phase. Further, there are studies examining neural correlates of JOL did not observe any difference related to the amplitude of this component among JOL levels (Irak et al., 2020). Therefore, further investigations focusing on the relationship between N100 amplitude and episodic memory processes is needed to interpret the observed difference in this study.

The P100 component was only detected at the parietal site with the latency of 95-145 ms. There was no significant difference in P100 amplitude among JOL levels, or hemispheres. Similar to the N100 component, P100 is an early component associated with perceptual and sensorial processing (Hillyard, 1985). However, unlike N100, it does not require discrimination to manifest. In other words, it can be evoked when stimuli in the attended channel are detected. Additionally, it is known that N100 has anterior and posterior components, while P100 is primarily a response generated from occipito-temporal areas (Luck & Kappenman, 2012). Based on these characteristics, the detection of the P100 component primarily in posterior channels and the absence of inter-response or inter-hemispheric differences in amplitude are consistent with the literature and suggest a gating function in information processing.

Another component detected for distinct JOL levels is P200. This component elicited with a latency of 140-195 ms in frontal, fronto-central, central sites, and with the latency of 190-230 ms in the parietal site. The main effect of hemisphere was found in frontal and fronto-central sites. In both sites, it was observed with greater amplitude at the midline. The P200 component is associated with post-perceptual selective attention processes (Luck & Kappenman, 2012). It has been reported that this component may also be related to emotional valence (Yuan et al., 2007), deviance (or oddity) detection (Yuan et al., 2008), and inhibitory control (Chen et al., 2008) processes. Furthermore, in a series of studies examining retrieval-induced forgetting, it has been found that the retrieval of practiced items affects the familiarity level of unpracticed items and is associated with a decrease in P200 amplitude (Spitzer & Bäuml, 2007; Spitzer et al., 2009). Similarly, in a study using mathematical problems as stimuli (Paynter et al., 2009), successful retrieval performance was found to be associated with peaks in the right frontal area at a latency of 180-280 ms (P200) and in the fronto-central area at a latency of 300-550 ms (P300). However, these responses were not present during unsuccessful retrieval. The authors proposed that P200 may be associated with the decision-making processes involved in assessing the familiarity

of the stimulus and thus the subsequent processes to be carried out for stimuli with high familiarity. Indeed, other ERP studies on metacognitive processes have found that P200 and P300 are significantly associated with monitoring processes during verbal memory performance (Błaszczak et al., 2018; Irak et al., 2019; Irak et al., 2020).

The results of the present study regarding P200 amplitude seem to support these previous findings (Irak et al., 2019; Paynter et al., 2009; Spitzer et al., 2009). P200 may index a rapid familiarity assessment. It should be noted that participants performed JOL assessments in the delayed JOL condition. Therefore, no significant differences in responses were expected for this component. Thus, it can be concluded that the hypothesis related to this component in the study has been confirmed.

P300 was another component elicited for distinct JOL levels with a latency of 270-400 ms. No significant differences were found in terms of P300 amplitudes among the JOL levels, however there were interhemispheric differences in the fronto-central and parietal sites. In the fronto-central site, greater amplitude was observed in the midline compared to the left hemisphere. In the parietal site, the amplitudes were found to be greater in the right hemisphere, followed by the midline, the left hemisphere, respectively.

P300 is a component that can be observed in the frontal, central, and parietal sites approximately 300-500 ms after the presentation of a target stimulus in classical or modified oddball paradigms. It is known that the amplitude of this component increases from the frontal site towards the parietal site (Johnson, 1993). P300 is a conscious response to unexpected situations that are incompatible with the current mental representations (Polish, 2012). It is well-established that this component is associated with cognitive processes such as context updating (Polish, 2003), cognitive control (Chen et al., 2008), decision-making (Twomey et al., 2015), and risk evaluation (Gao et al., 2023). The amplitude of P300 can increase or decrease depending on the level of unexpectedness, difficulty, and emotional valence of the stimulus material (Polish, 2007; Zhang et al., 2021).

P300 has been emphasized as an important component for the memorability of stimuli. That is, stimuli that elicit a greater P300 amplitude are encoded better and are easier to retrieve (Donchin, 1981). The ability to encode a stimulus more effectively requires a change in the alertness level of the individual. For this, the individual

compares the stimulus in question with preceding stimuli to determine if it deviates in any subjective importance, and if a deviation is perceived, an updating process takes place. P300 is a component that indexes these processes related to memory and learning (Polish, 2012). It has also been reported that this component reflects the motivational importance of the encountered stimulus for the individual (Gao et al., 2023). Thus, the individual's level of motivation during stimulus processing is also a factor that can influence the characteristics of P300.

It is observed, in the present study, that P300 is elicited for all JOL levels. However, no amplitude differences were found among these levels. Consistent with previous studies, it can be suggested that participants rapidly performed a familiarity assessment regarding whether they had encountered the presented stimuli before at this stage. Considering that there were no new stimuli among those presented in the delayed JOL condition, the lack of observed differences in P300 amplitudes may indicate that participants were effective monitors. Additionally, as P300 is an endogenous component, it is influenced by how attentional resources are allocated. Therefore, the absence of significant amplitude differences in P300 may be related to participants processing all stimuli with the same level of attention and motivation.

The N200 component was detected with the latency of 235-310 ms in the frontal, fronto-central, central sites, and with the latency of 230-270 ms in the parietal site. There was no significant difference in N200 amplitudes among JOL levels, but greater amplitudes were found in the midline compared to the right hemisphere in the frontal, fronto-central, and parietal sites. The N200 component is associated with the processing of incongruent and irrelevant stimuli, therefore it is considered to be related to conflict monitoring (Donkers & Van Boxtel, 2004; Nieuwenhuis et al., 2003). Conflict is conceptualized as a situation arising from the simultaneous occurrence of competing responses (Yeung & Cohen, 2006). When performing a cognitive operation, the presence of salient or novel events (or stimuli) may create a conflict that needs to be detected first, and then resolved. Conflict monitoring has been predominantly studied using tasks such as the flanker task, go/no-go task, and oddball paradigm (for a review see Folstein & Van Petten, 2008). In these tasks, participants are believed to consciously evaluate the correct response to the target stimulus before responding, and this is indexed by the N200 component (Chen et al., 2008; Nagy et al., 2003). The N200 component is associated with detecting deviance in the attended channel, and

changes in the unattended channel(s) do not elicit N200 (Opitz et al., 1999). However, in the present study, participants were not required to engage in processing competing stimuli with the target stimulus. Therefore, it can be inferred that participants continued to monitor their responses while making JOL assessments, which is consistent with findings from previous studies (Irak et al., 2020).

Furthermore, it is obvious in many studies that N200 forms a complex with the P300 component (Golgeli et al., 1999; Nagy et al., 2003). The conflicts that N200 indexes must be inhibited (or resolved) in order to continue task-relevant operations, and it has been emphasized that the subsequent P300 may be related to that inhibitory control (Chen et al., 2008). The results of the present study also showed that N200 is followed by P300 (N200-P300 complex). Therefore, it can be concluded that participants were able to continue task-relevant processing while evaluating the familiarity of the stimuli.

At the central and parietal sites, a negative component was elicited with 330-500 ms latency. However, contrary to the hypothesis, no significant differences were observed in terms of the amplitude of this component either over the central or parietal site. We expected this component to be elicited with higher amplitude for high level of JOL (“Definitely able to remember” in this study) compared to other levels. The hypothesis was formulated based on the (ERP) findings of psychophysiological studies investigating JOL. For example, it is stressed that the retrieval of contextual details is important while making JOL assessments since recognition-related ERP components showed different patterns for distinct levels (Skavhaug et al., 2013). Therefore, we expected this component to be elicited with greater amplitude since the processes after the early time window following stimulus presentation (approximately after 300 ms) would be associated with recollection.

Skavhaug et al. (2010) detected a slow negative wave over posterior electrodes in the contrast of JOL levels, spanning from 1300 to 1900 ms, and reported that the amplitude of this component was larger for high JOL responses. This finding was interpreted as reflecting a greater amount of accessed information during the reporting of high JOL responses, which is consistent with findings from source memory studies (Heil et al., 1997; Rösler et al., 1995). These studies have shown that the amount of retrieved information manifests itself positively correlated with the amplitude of a

negative slow wave, particularly over posterior areas (Late Posterior Negativity, LPN) (Friedman et al., 2005). LPN, on the other hand, may reflect the effort to reconstruct the conjunction of all features of the information encountered during the encoding stage, regardless of the success of the retrieval attempt (Johansson & Mecklinger, 2003). It has also been reported that this component has subcomponents associated with different cognitive processes and is functionally more heterogeneous than what has been mentioned above (Herron, 2007). The interpretations of Skavhaug et al. (2010) regarding the observed late slow wave are compatible with LPN in terms of topography, polarity, and function. In a subsequent study, Müller et al. (2016) demonstrated that this response can be captured at earlier time window with a delay-JOL condition. Indeed, the results of this study also indicate the elicitation of a negative component in the 330-500 ms over central and parietal sites. However, no significant differences were found between responses which contradicts to the hypothesis. This might suggest that participants engaged in retrieval attempt for all stimuli after quickly performing the familiarity assessment and, this negative component may serve as an indicator of cognitive effort and the allocation of attentional resources invested for this attempt, independent of the success of retrieval. The absence of any significant difference among distinct JOL levels might stem from such an aspect of the assessment.

4.3.2 Discussion of ERP results in the recognition phase. As hypothesized, a negative slow wave, treated as FN400, detected in the frontal, fronto-central and central sites with the latency of 350-600 ms. The comparison analysis among distinct hit responses (“Definitely able to remember-hits”, “Uncertain-hits”, “Definitely not able to remember-hits”) revealed no significant differences in the amplitude of this component which confirmed another hypothesis of the study. These findings are also consistent with the ERP results obtained in the JOL phase; no significant difference was found among distinct JOL levels in terms of the amplitudes of the P200 and P300 components, which were associated with familiarity assessment. Therefore, it can be reiterated that the participants in this study demonstrated effective monitoring of familiarity.

Beside FN400, and a positive slow wave, treated as parietal old/new effect, was detected in the parietal and parieto-occipital sites with the latency of 450-700 ms. The results showed that the “Definitely able to remember-hits” elicited smaller amplitudes

for this component compared to the other two types of hit responses, contradicting the hypothesis related to this component.

It has been demonstrated that the parietal old/new effect in recognition memory is influenced by the confidence level linked to the response pertaining to the target information. Addante et al. (2012), for instance, measured participants' confidence levels on their old/new judgments and found that the parietal old/new effect was only elicited for the responses provided with high confidence level. Another important finding of the study is that even when the target information is not successfully retrieved, contextual details could still be recalled. Thus, our interpretation for the results relating parietal old/new effect is as follows: In all three conditions (distinct hit responses), after the familiarity assessment, participants may have utilized the interval for the response with the details they could access to retrieve the target information. They may have engaged in more extensive search and cognitive effort while reporting the other two hit response types than for "Definitely able to remember-hits". It is also consistent with our interpretation of the difference observed in N100 amplitude during the JOL phase that "Definitely able to remember" responses elicited it with greater amplitude.

On this occasion, we think the lack of a difference in the amplitude of the negative component (330-500 ms) elicited in the JOL phase should be reconsidered. Our explanation is as follows: during the JOL phase, participants were not specifically instructed to engage in retrieval of the target information. In fact, retrieval is not necessary for JOL (Dunlosky & Nelson, 1992). However, participants who performed the familiarity assessment may have subsequently made retrieval attempts in order to remember that information. Therefore, our interpretation regarding the absence of a difference in that negative component is, once again, related to the lack of differentiation in the level of cognitive effort exerted by participants. However, during the recognition phase, participants are required to overtly provide their responses regarding the target information. In other words, in addition to the presumed retrieval attempts, they are asked to report an outcome of this cognitive effort. Therefore, we think this may be the reason that the difference that was not appeared prominently during the JOL phase manifest during the recognition phase.

The cumulative evaluation of the results obtained from the recognition phase reveals that the metacognitive judgments conducted in the delayed condition were executed mostly in a retrieval-based manner. This noteworthy finding aligns with both the dual memories hypothesis (Nelson & Dunlosky, 1991) and the self-fulfilling prophecy hypothesis (Spellman & Bjork, 1992), rendering valuable insights into the underlying cognitive mechanisms. Upon meticulous examination of the behavioral and electrophysiological findings, it becomes evident that stimuli assigned higher levels of JOL demonstrated superior recognition performance during the memory test in the delayed JOL condition, unequivocally implicating that familiarity could not be the sole mechanism governing this assessment, rather access to the information seems to be the key.

4.4 Limitations and Strength of the Present Study

Whilst the question of whether gender is a confounding variable remains controversial in the ERP literature, it should be noted that the current sample was not balanced in terms of the number of male and female participants. Previous studies have reported that ERP components associated with top-down processes of attention or higher-level cognitive processes may differ across genders (Nagy et al., 2003; Yuan et al., 2008). Gogeli et al. (1999) also reported similar results when examining such differences in the population of Turkey. Therefore, all results and interpretations should be taken with caution, considering the potential influence of this variable.

Another significant limitation is that, although EEG recordings were obtained during the learning phase, the data from this phase were not processed or analyzed. This absence of analysis has particularly led our interpretations regarding some of the findings obtained during the JOL phase to be speculative. Therefore, for the future ERP studies, we emphasize the importance of conducting analyses pertaining to the learning phase to investigate whether there are any differences in encoding efficiency when JOL is measured under delayed conditions.

Lastly, we measured the JOL with categoric choices in this study. However, previous studies have mostly employed Likert or other types of rating scales (Irak et al., 2020; Müller et al., 2016; Skavhaug et al., 2010). Although the results of the study are largely consistent with the literature, there are also novel findings. Whether such findings might be attributed to the use of this distinct paradigm remains unanswered.

Therefore, it is important to investigate JOL comparatively using different paradigms to enhance our understanding of the cognitive mechanisms underlying this metacognitive process.

On the other hand, this study provides important findings regarding the cognitive and neural foundations of JOL. For instance, individuals are able to make effective and accurate assessments about their own memory processes after a while following learning. Particularly, the difference found in favor of high JOL level hold significant importance for educational settings in terms of measurement and evaluation of the learning material (Ozturk, 2017). This is because higher accuracy is observed in the delayed condition for information deemed to have been sufficiently learned. Moreover, certain models have been proposed for monitoring the information that is considered not to have been learned well enough, and for facilitating a more effective learning of this information through metacognitive regulations (Thiede et al., 2019; Guzel & Basokcu; 2023). According to these models, when viewed from an educational context, the teacher's judgments regarding students' learning processes play a critical role in the effectiveness of learning and the achievement of students. In essence, when the teacher monitors the effectiveness of learning and employs appropriate control (or intervention) methods based on this monitoring, integrated with the student's own metacognitive monitoring processes, achieving the targeted success can be facilitated. Therefore, the results of the present study could be taken into consideration for the development and application of strategies and programs that target the learning processes.

Further, although the present study was conducted with a healthy sample, it also provides important findings for clinical populations. In certain psychiatric and neurological patient groups, impairments in memory (or other cognitive processes) may be present, while metacognitive processes remain intact (David et al., 2012; Illman et al., 2016; Souchay et al., 2006). Drawing from this picture, the development of neuropsychological rehabilitation programs based on metacognitive skills can be considered for such clinical populations. Through the implementation of these programs, these patients, who are capable of making accurate assessments regarding their cognitive processes, may be able to improve their memory (or other cognitive processes) performance (Clare et al., 2004).

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