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Article *in* Consciousness and Cognition · August 2020

DOI: 10.1016/j.concog.2020.103000

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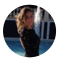
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A Study on Executive Functions Resources

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In Press, Consciousness & Cognition

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Abstract

Previous studies demonstrated that memory accuracy is affected by the availability of the individual's cognitive resources. A predominant role in complex cognition has been postulated for executive functions (EF). The aim of the present study was to verify if there are differences in remembering a crime with respect to the individual's EF availability (i.e., Shifting, Inhibition, and Updating). We showed participants a video of a violent crime. Next, they were requested to imagine to be an eyewitness of the crime and report a testimony as detailed as possible. A subsequent memory test was run after ten days. EF resources were assessed in a third session through three neuropsychological tasks. Findings showed that high EF individuals reported more correct details and fewer memory distortions (i.e., omissions and commissions) than low EF individuals. Our results underline that individual EF resources are implicated in the recalling of an event.

Keywords: *Executive Functions, Shifting, Inhibition, Updating, Memory Errors, Eyewitness.*

Introduction

The idea that memory for an event is prone to errors is largely known (e.g., Loftus, 2005). In the scientific literature, there are numerous studies showing the extent to which memory accuracy depends on many factors, e.g. the context in which the subject has encoded the event (Arnold & Lindsay, 2002) or suggestions provided by others (Loftus & Pickrell, 1995). Indeed, our memories are not literally reproduced but they are reconstructed when they are recalled (e.g., Frenda, Nichols, & Loftus, 2011; Howe, Knott, & Conway, 2017; Nash & Wade, 2008). During this reconstructive process, a person might unintentionally report false memories and memory distortions (e.g., Loftus, 2005). In other words, an individual could either remember details or recall a whole event that never occurred, or remember details in a different way from the actual event (e.g., Roediger & McDermott, 1995). Moreover, the information of an event could not only be omitted, distorted or fabricated, but the same event could also be remembered in many different ways by different people (Leding, 2012). In light of this, understanding the individual factors that lead to different recollections of the same event would be crucial to both memory researchers and legal professionals who have to reconstruct past experiences (i.e., crimes) from eyewitnesses' memory accounts. Indeed, in real-context eyewitness situations, it is not possible to determine what originally happened in the crime scene and this makes it difficult to assess the reliability of testimonies. Research has shown that eyewitness' memory errors (i.e., omissions: do not report details of the event; commissions: details partially or completely wrong) are the most problematic issues for testimonies, contributing to wrongful convictions (Saks & Koehler, 2005; Smeets, Candel, & Merckelbach, 2004). As a consequence, being able to determine the quality of eyewitnesses' recollections based on individual differences of people assessed in forensic proceedings could definitely be useful for legal purposes.

Despite the large number of studies on the formation of spontaneous memory distortions[1] (e.g., Ackil & Zaragoza, 1998; Loftus, Miller, & Burns, 1978; Loftus & Pickrell, 1995; Otgaar &

Candel, 2011; Otgaar, Howe, Peters, Sauerland, & Raymaekers, 2013), a limited amount of research has attempted to figure out whether the tendency to report memory errors may be related to individual differences in cognitive capacities, like for instance the individual's Executive Function (EF) resources (e.g., Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000).

Individuals Resources and Memory Errors

Recently, a small number of studies have shown that EFs are implicated in the formation of memory distortions and false memories (e.g., Gerrie & Garry, 2007; Gonsalves & Paller, 2002; Kopelman, 1999; Leding, 2012; Marsh, Balota, & Roediger, 2005; Melo, Winocur, & Moscovitch, 1999; Peters, Jelicic, Verbeek, & Merckelbach, 2007; Schacter, 1999; Schacter & Slotnick, 2004). Studies have addressed such an issue by measuring the individuals' EF resources in terms of Working Memory[2] (WM) (e.g., Bowler & Lezak, 2015) and have demonstrated that such resources (i.e., WM resources) predict the individual's proneness to report memory distortions (e.g., Bixter & Daniel, 2013; Peters, Jelicic, Verbeek, & Merckelbach, 2007; Watson, Bunting, Poole, & Conway, 2005). Overall, the predominant result is that low EF individuals (i.e., individuals with a poor WM performance) generally displayed more memory distortions than high EF individuals. This finding has been replicated by using different false memory evaluation methods, like the Deese/Roediger-McDermott paradigm (e.g., Peters, Jelicic, Verbeek, & Merckelbach, 2007; Watson, Bunting, Poole, & Conway, 2005), visual materials (Gerrie & Garry, 2007) and the misinformation paradigm (e.g., Jaschinski & Wentura, 2002; Zhu et al., 2010).

In the Deese/Roediger-McDermott paradigm (DRM; Deese, 1959; Roediger & McDermott, 1995), participants have to remember lists of associated words (e.g., bed, rest, awake, tired, dream, wake, snooze, blanket, doze, slumber, snore, nap, peace, yawn, drowsy). The words in these lists (e.g., 12 or 15 words) are related to a critical word, called the *critical lure*, not presented in the list previously studied (i.e., sleep). After the list presentation, participants are involved in a memory task (i.e., recall or recognition task). Some scholars use a recall task during which participants have to recall all the studied items (*old words*). Other scholars use a recognition task requiring participants to complete a task composed by old words, unrelated words not presented in the study phase (*new words*) and related words not presented in the study phase (*critical lures*). During the recognition task, participants are requested to recognize the words previously studied among the old words, the new words, and the critical lures. Studies that have used this paradigm have demonstrated that participants typically remembered many of the old words and regularly reported false memories, by remembering the critical lures as old words (e.g., Peters et al., 2007). Additionally, Watson, Bunting, Pole, and Conway (2005) demonstrated that, when participants were warned about a possible DRM effect, high EF individuals were more able to avoid false memories during the memory test than low EF participants. By contrast, when no warnings were provided, no statistical differences in the recall of people with high and low EF resources were found.

Other studies have shown a similar pattern of results using more ecologically valid stimuli (e.g., Jachinski & Wentura, 2002; Gerrie & Garry, 2007; Zhu et al., 2010). For example, research using the three-stage misinformation paradigm found a negative correlation between participants' EF resources (i.e., WM) and a measure of memory distortions reported in the recall of the original event (e.g., Jachinski & Wentura, 2002; Zhu et al., 2010). In these latter studies, the procedure was as follows. Participants had to watch an event and read a report containing some video related false information. Then, they were requested to write down what they remembered having seen. The authors demonstrated that high EF participants were less likely to integrate misleading information into their memory reports for the actual event than low EF participants. More recently, also Gerrie and Garry (2007) showed that high EF participants were more able to avoid false memory formation for missing information than low EF individuals. The authors asked participants to watch a short movie (i.e., a woman making a sandwich) in which the crucial information was inserted or removed. Two versions of the movie were used: (i) the crucial present version, in which non-crucial information (e.g., cutting the sandwich in half) was removed and (ii) the crucial absent version, in which the crucial information (e.g., placing the two parts of sandwich in together) was removed. Individuals' memory was tested with a task in which participants had to indicate whether a set of clips (i.e., old clips: clips of actions actually see in the video and missing clips: clips of action never seen in the video) had been presented or not in the movie. The main finding was that high EF participants were more able to recognize whether the information was seen in the video than low EF participants. Such an effect was found particularly strong for the crucial aspects of the event.

An explanation of the above-mentioned findings has been related to the individual's source monitoring ability (SM; Johnson, Hashtroudi, & Lindsay, 1993). Memory researchers (e.g., Peters et al., 2007; Watson, 2005) have indeed shown that memory errors (i.e., commissions, false memories) can derive from the inability to distinguish between two different but similar sources of information. Indeed, when two sources (i.e., real vs. only imagined) shared similarities between each other and they are automatically activated at the retrieval, people can experience confusion between such sources that results in source monitoring errors (Roediger, Watson, McDermott, & Gallo, 2001). It follows that high EF individuals were more able than low EF individuals to engage in a source monitoring task due to their higher abilities to maintain relevant information in mind, reduce interference between similar sources and exclude intrusive and irrelevant information (e.g., Gerrie & Garry, 2007; Leding, 2012; Peters et al., 2007; Unsworth & Brewer, 2010).

Recently, another line of research has investigated the influence of EF resources in the formation of memory errors for negative and neutral events (e.g., Mirandola, Toffalini, Cirielli, & Cornoldi, 2015; Osaka, Yaoi, Minamoto, & Osaka, 2013). These studies – by considering WM resources as an indicator of the individual's availability of EFs - have shown that individual resources play a critical role also in the occurrence of false memories for emotional events. To illustrate, Osaka and colleagues (2013) have found that events with different valence (i.e., negative vs neutral) activated different neural areas and that negative valence was associated with inhibition ability (see also, Van Dillen & Koole, 2009). In other words, compared with neutral information, negative information was more difficult to be inhibited, especially when individuals did not have a large availability of cognitive resources. In their study, high EF participants made fewer memory errors for negative events than low EF participants, whereas for neutral events no significant differences between the two groups were found. The authors argued that the limited availability of resources of low EF participants and the demanding inhibition process required by negative events rendered such people more prone than high EF people to develop memory distortions. Similar findings have been replicated in a more recent study of Mirandola and colleagues (2015). The authors justified their results by stating that the difficulty experienced by low EF individuals in controlling and managing different information (i.e., presented vs not presented and associated) was caused by a lower ability to recognize sources similar to each other in terms of content, especially in case of negative events.

Finally, studies conducted on people with neuropsychological or aging deficits have displayed a link between these deficits in cognitive functions (i.e., EFs) and false memories (e.g., Melo, Winocour, & Moscovitch, 1999; Raz, 2000), showing that damages to brain structures responsible for executive functioning increased the frequency of false memories (i.e., false recognition in DRM paradigm) because of an impairment of the ability to distinguish between false and true memories. Further support to the link between aging impairment in EF and memory distortions has been provided by recent work (e.g., Kersten, Earles, Aucello, Tautiva, McRostie, Brydon, & Adaryukov, 2018) making it reasonable to extend the conclusions of studies on people with brain damages to samples of healthy individuals. Specifically, Kersten and colleagues (2018) found that older people tend to report more commission errors than younger people, especially when they have a low amount of executive functioning resources. Thus, this study has also confirmed once more the link between EF resources and memory distortions.

Overall, research has mainly demonstrated that individual EF differences predict memory accuracy for an event by using a measure of individuals' WM resources. Very few studies have addressed this issue considering an aggregate measure of EFs resources as suggested by Miyake and colleagues' model (2000) to assess this construct (e.g., Kersten et al., 2018). Thus, by following this approach, the aim of the current study is to further investigate the relationship between the individuals' EF resources and recall for a crime experience.

Executive Functions

Executive Functions (EFs) have been defined as "mechanisms that modulate the operation of various cognitive subprocesses and thereby regulate the dynamics of human cognition" (Miyake et al., 2000, p. 50). They are implicated in the execution of complex cognitive processes, such as attentional control, problem-solving, and task-set control (Carpenter, Just, & Reichle, 2000; Carretti, Bellacchi, & Cornoldi, 2010) and they are a core part of self-control ability that is essential for everyday activities (Curci, Lanciano, Soleti, & Rimé, 2013; Curci, Soleti, Lanciano, Doria, & Rimé, 2015; Mischel et al., 2011; Moffitt et al., 2011).

One of the most important theoretical frameworks related to EFs is the multicomponent model of Working Memory (WM; Baddeley, 1986; Baddeley & Hitch, 1974). In this model, Baddeley has identified three components: The phonological loop, the visuospatial sketchpad, and the central executive. The first two components, called slave systems, are involved in the maintenance of speech-based and visuo-spatial information. The central executive is a central structure responsible for the control and regulation of cognitive processes, like EFs (see also, Miyake et al., 2000). Despite the large heuristic value of Baddeley's model (1986), understanding the organization and the role of EFs during the execution of cognitive tasks (such as memory recall of everyday experiences) is a complex issue (e.g., Monsell, 1996).

Miyake and colleagues (2000) have conducted an important study focusing on how EFs intervene in the dynamics of human cognition. In this study, the authors explained such dynamics by taking into account the three EFs considered as the most relevant for the central executive component of Baddeley's WM system (e.g., Berger, Richards, & Davelaar, 2017; Miyake et al., 2000; Miyake and & Friedman, 2012): *Updating and monitoring of working memory representations*, *Shifting between tasks or mental sets*, and *Inhibition of prepotent responses*

(Baddeley, 1996; Berger, Richards, & Davelaar, 2017; Logan, 1985; Lyon, Krasnegor, & McMenaninm, 1996; Miyake et al., 2000; Smith & Jonides, 1999).

More specifically, *Updating* is the most related function to WM (Jonides & Smith, 1997; Lehto, 1996). It concerns the ability to monitor and code the incoming and relevant information for the execution of a task. Moreover, it refers to the capacity to change the old and irrelevant information in WM into newer and more relevant information through an active manipulation (Lehto, 1996; Morris & Jones, 1990). In other words, this process requires a "*temporal tagging*" (Miyake at al., 2000, p. 57) to enable recognition of old and irrelevant information and its updating in WM (Jonides & Smith, 1997). The EF *Shifting*, also called "attention switching" or "task switching", pertains to the ability to switch back and forth between different tasks, operations or mental sets (Monsell, 1996). This process requires the disengagement of an irrelevant task set and the activation of a relevant one, and results in a temporal cost (e.g., Jersild, 1927; Rogers & Monsell, 1995), especially when the process is not driven by external prompts (Spector & Biederman, 1976). Furthermore, Shifting involves the capacity to overcome proactive interference or negative priming (Allport & Wylie, 2000). The last EF, *Inhibition*, concerns the ability to intentionally suppress dominant, automatic and prepotent responses when required (Miyake et al., 2000). Beyond this first type of inhibition, there is another process strongly correlated with the first, which is not necessarily a deliberate process. This is known as reactive inhibition and refers to a decrease in activation level due to deactivation (i.e., negative activation) (Logan, 1994).

Interestingly, Miyake and colleagues (2000) showed that the aforementioned three EFs are simultaneously distinct and not distinguishable from each other. On the one hand, the authors demonstrated that each of them can be considered as completely independent from the others. On the other hand, they found high correlations among the three EFs in the execution of complex cognitive tasks. This stringent intercorrelation was explained considering the commonalities shared by the three EFs. For example, all functions entail inhibitory processes of non-relevant information and sustenance of pertinent information in WM. Taken together, evidence bears up a twofold consideration: The role of each EF needs to be considered as strictly associated to each other (Dempster & Corkill, 1999; Duncan et al., 1996, 1997; Engle et al., 1999a; Kimberg & Farah, 1993; Zacks & Hasher, 1994) and individual EFs differences need to be assessed by administering multiple tasks to aggregate into a single measure of EF (e.g., Miyake et al., 2000; Miyake & Friedman, 2012).

Following the above reported review, our study intended to test the role of the individual's EF resources - assessed through three executive tasks -- on memory recall for an everyday event of forensic relevance. Indeed, to the best of our knowledge, studies so far have mainly investigated the link between EF resources and memory accuracy by adopting a unique and more general measure of individuals' WM functioning. We expected that the adoption of a complex measure of EF would enable us to overcome this limitation. Note that, we selected in our experiment the three EFs of Updating, Shifting, and Inhibition among a larger number of EFs. Indeed, EFs refer to a set of mental processes, such as problem-solving, planning, and selective attention abilities (e.g., Diamond, 2013). We chose these three EFs for two reasons. First, these three unroll the core role of the central executive component of the WM system (e.g., Baddeley, 1986; Miyake et al., 2000; Miyake and & Friedman, 2012). Second, studies have demonstrated that these EFs are the most implicated in superior cognitive performance, such as memory recall (e.g., Burgess & Simons 2005; Diamond, 2013; Espy 2004).

The Present Study

Aims and Hypotheses

By integrating findings presented above, the present study had the goal to verify whether and how the individual's availability of EF resources can predict memory accuracy for a mock crime video. At odds with studies conducted until now that have tested the role of EF resources only in terms of WM ability, our study aimed to adopt a comprehensive measure of different components of EFs (i.e., Updating, Shifting, and Inhibition). More specifically, our study aimed to understand how EF resources can be involved in the recall of an event in terms of correct details, omission and commission errors reported. To this purpose, we showed participants a mock crime video[3] and, immediately after this presentation, we requested them to provide a report of the event and answer some questions about it. Ten days later, participants' memory was tested again. In a last session, each participant was invited to come back to the laboratory and performed some neuropsychological tasks to assess the individual's EF resources in terms of Shifting, Inhibition and Updating. In accordance with Miyake and colleagues' study (2000) that showed interchangeable roles of EF and their strongly associated contribution within the cognitive processing, we divided participants into low and high EF resources based upon their scores on all three EF tasks.

In line with previous studies, we expected thus that high EF individuals – classified through this complex assessment – exhibit a higher correctness score than low EF individuals (Hypothesis 1). We also expected that high EF individuals reported fewer omission and commission errors than low EF individuals (Hypothesis 2).

Method

Participants and Design

Using G*power (Faul, Erdfelder, Lang, & Buchner, 2007), an a priori power analysis for a 2 x 2 mixed ANOVA with a power of 0.80 and medium effect size ($f = 0.25$) indicated that a sample of 34 participants was required. A total of 112 students[4] (women = 86.6%, $M_{age} = 21.49$, $SD = 3.11$) were recruited at the Department of Education, Psychology, Communication of the University of Bari "Aldo Moro". Twenty participants were excluded following the procedure described at the beginning of the section on Results, leaving 92 participants (women = 85,9%, $M_{age} = 21.38$, $SD = 2.43$). Specifically, we extracted the extremes of the distributions for the scores of the neuropsychological tasks, and excluded participants scoring around the median point of these distributions, in order to have two well-defined subgroups corresponding to high vs. low EF resources. Hence, our study used a 2x2 mixed model design with EF resources (high vs low) as a between-subjects factor and memory test-retest (T1 vs T2) as a within-subjects factor. The dependent variables were the correctness scores, omissions and commissions scores in cued and free recall tests run immediately after the event (test) and ten days later (retest). The ethical committee of the Department of Education, Psychology, Communication of the University of Bari "Aldo Moro" approved the study (No. ET-19-11). The study was preregistered (https://osf.io/v49rf) and all the data and materials can be accessed on the Open Science Framework: https://osf.io/q7gj9/.

Measures and Procedure

Participants involved in the study completed three sessions. The first one required approximately thirty minutes during which they watched a video and then performed two memory tests. After ten days, the second session took place and it contained the same memory tests of the first session. In the final session, three neuropsychological tasks were administered in order to evaluate the EF resources. Before starting the experiment, each participant filled out the Informed Consent and signed for a voluntary participation.

Session 1

Participants first performed a screening phase. They were assessed with the Positive and Negative Affect Schedule-Trait and State (PANAS-T and –S; Terraciano, Mc Crae, & Costa Jr, 2003; Watson, Clark, & Tellegen, 1988) to exclude individual differences in terms of emotional trait and state. The PANAS-S was also administered after the mock crime video to assess the emotional impact of the video.

The PANAS-T and S (Terraciano et al, 2003; Watson et al. 1988). These scales evaluate the emotional state of participants along two dimensions: The Positive Affect (PA) and the Negative Affect (NA). Both PANAS-T and S consist of twenty 5-point items (0 = not at all, 4 = completely). The PA-T (Cronbach's $\alpha = .72$) and NA-T (Cronbach's $\alpha = .88$) assess, respectively, the positive and negative level of emotions usually felt by people. The PA-S (Cronbach's α = .85) and NA-S (Cronbach's α = .91) indicate the affective state that participants felt during the compilation. The score along the four dimensions were summed up.

Mock Crime Video. After the screening phase, participants attentively watched a mock crime video (approximately 2 min 30 sec). The instructions were to pay attention to the video. We employed the video clip used in another memory study (Mangiulli, Lanciano, van Oorsouw, Jelicic, & Curci, 2019). At the beginning, the video shows two men discussing something. The video then continues with a violent scene in which the two guys have a fight that ends with the murder of one by the other. After the video, participants completed again the PANAS-S (Terraciano et al., 2003; Watson et al., 1988).

Memory test phase (T1). After filling in the emotional questionnaire, participants performed two memory tests. All participants had to imagine to be an eyewitness of the crime and to be in a police station to provide a testimony. The first memory test was a free recall task during which participants had to write down all information and details they remembered about the video clip. Subsequently, participants answered fourteen cued-recall questions (i.e. *What was the victim wearing?*) having the same instruction of the free recall task.

Session 2

Memory test phase (T2). After ten days, participants came back to the laboratory and performed again the same two memory tasks (i.e., free and cued recall) of session 1.

Executive Functioning Assessment

Three neuropsychological tasks were administered to each participant. The first two were paper and pencil tasks, the third one was a computerized task of the Psychology Experiment

Building Language 2.0 battery (PEBL 2.0; Mueller, & Piper, 2014). When participants finished this last session, they were thanked and individually debriefed.

The Phonemic Fluency (Novelli et al., 1986). This task requires participants to produce as many words as possible in 60 seconds, beginning with a letter given by the experimenter. This happens for three different letters (C, P and S). Participants can recall any words except names of people and cities. The score of this task is the average the number of words produced for the letters. This score does not include repetitions and intrusions. Repetitions refer to words repeated more times, while intrusions are words that do not conform with the instructions. The task is typically employed to assess the ability of Updating (Miyake et al., 2000).

Plus-Minus Task (Jersild, 1927; Spector & Biederman, 1976). This task consists of three trials of mathematical operations. In the first trial, participants add the value of three to a set of randomly preselected numbers. In the second trial, they subtract three from the target numbers. In the third and crucial trial, participants switch between addition and subtraction operations. This last trial starts with adding three to the first number, continues with subtracting three to the second number and proceeds alternating these two operations. For each participant, the experimenter records the time to complete the set of operations. The final score is obtained by subtracting the average time of the first two trials from the time to complete the last trial. This task is used to measure the Shifting ability (Miyake et al., 2000).

Go-NoGo Task (Bezdjian, Baker, Lozano, & Raine, 2009). In this task, participants have to respond to some stimuli (Go stimuli) and make no response for others (NoGo stimuli). Participants watch on a computer screen a square divided into four squares where the letters P or R randomly appear. In the first block (P-Go) the Go stimuli are the letter P, so participants are instructed press the mouse every time the P appears on the screen and do not press when the letter R appears. In the second block (R-Go) the Go stimuli are the letter R, so participants are instructed press the mouse when the letter R appears and press nothing when the letter P appears. Both first and second blocks are composed of 160 stimuli during which the letter remains on the screen for 500 milliseconds. The score is the average commission errors reported at the two blocks. This task assesses the Inhibition ability (Miyake et al., 2000).

Memory Recall Scoring

In order to avoid the possibility of any observer expectancy effect, the memory recall scoring was performed by the first author and a student assistant before the division of the sample into the two experimental groups (i.e., low and high EF resources). Moreover, the student assistant was completely blind to the experimental design.

Cued Recall

Each cued-recall answer was scored to have indices of correct details, omissions and commissions. To calculate the correct details reported, one point was given for each correct answer (e.g., *"What was the victim wearing?" "He was wearing a black jacket, white skirt and black shirt"*), while half a point was assigned for a partially correct answer (e.g., "*He was wearing a black jacket"*). When participants gave no answer (e.g., "*I do not remember"*) or a completely wrong answer (e.g.. "*He was wearing a green suit"*), a score of zero was assigned. The maximum score obtainable was 14. For each participant, proportions were calculated by dividing the score obtained by 14. Additionally, errors in terms of omissions and commissions were calculated. For the omissions score, one point was assigned when the participant provided no answer (e.g., "*I do not remember"*). For the commissions score, one point was assigned when the participant introduced new information which was no part of the mock crime video (e.g., "*He was wearing a green suit"*) or half a point when the participants provided a partially distorted answer (e.g., "*He was wearing a blue jacket, blue skirt and black shirt"*). The three memory indices at both T1 and T2 were scored by the first author and a student assistant. The ICC average measure for the number of correct cued recall details at T1 and T2 was .77 and .68 (both *ps* < .001); the ICC average measure of omissions and commissions for cued recall at T1 was respectively .79 and .78 (both *ps* < .001) and at T2 respectively .78 and .76 (both *ps* < .001).

Free Recall

Following a scoring system adopted in a previous study (Mangiulli et al., 2018), the mock crime video was divided into 50 critical units. Each unit referred to a critical action displayed in the video. In line with cued recall scoring, the free recall was scored as indices of correct details, omissions, and commissions. To have the correct details score, 1 point was assigned to each unit of information correctly reported (e.g., "*The murderer assaulted the victim from the back*"), while half a point was given for a partially correct unit (e.g., "*The murderer assaulted the victim*"). The maximum score obtainable was 50. In line with our cued recall scoring, proportions were calculated by dividing the number of correct details reported by the maximum score. Moreover, the omissions score was calculated by attributing 1 point for every unit of information not included in the recall. Finally, for the commissions score, 1 point was assigned when participants reported in their recall a completely wrong detail (e.g., *"The murderer was wearing a hat"*), while half a point was given when a distorted unit information was provided (e.g., "*The murderer killed the victim by using a gun"*). All the three free recall scores were calculated for T1 and T2 and by the first author and a student assistant. The ICC measure for correct details scores at T1 and T2 was .80 and .82 (both *ps* < .001); the ICC average measure of omissions and commissions at T1 was respectively .85 and .83 (both *ps* < .001) and at T2 respectively .86 and .88 (both *ps* < .001).

Results

Preliminarily, an inspection of the frequency distributions[5] of the three neuropsychological scores was run in order to create two subgroups of individuals with low versus high EF resources. Specifically, we selected from our initial sample (*N* = 112) of participants subjects (*N* = 92) scoring either below the first quartile or above the last quartile of score distribution for at least one of three EF tasks (i.e., Phonemic Fluency, Plus Minus Task, and Go/NoGo). On this sample, we calculated the rank distributions for the three tasks and then the ranks' average score for each participant in order to obtain our aggregate measure of EF. We thus had divided the sample into two subgroups of participants scoring respectively low (n = 46) vs. high (n = 46) EF resources with respect to the middle quartile of the aggregate score.

Screening Analysis

In order to examine individual differences in the emotional states of participants, PANAS-T scores were analysed through an independent sample *t*-test. The analyses showed no statistically significant differences between the two groups of participants (i.e., low vs. high EF resources) neither in the PA-T [M_{low} = 27.24, 95% CI [25.95, 28.53]; M_{high} = 27.30, 95% CI [25.82, 28.79]; $t(90) = -.07$, $p = .95$, 95% CI [-2.01, 1.88], $d = -.01$] nor in the NA-T scores [M_{low} = 12.11, 95% CI [9.59, 14.62]; M_{high} = 12.57, 95% CI [10.50, 14.63]; $t(90) = -.28$, $p = .78$, 95% CI [-3.67, 2.75], d = -.06] before the experimental session.

Affective Impact of the Mock Crime Video

In order to assess the affective impact of the mock crime on participants, 2x2 mixed ANOVAs with EF resources (low vs high) as a between subjects factor and pre-post mock crime video (pre-mock crime vs post-mock crime) as a within subjects factor were run on PANAS-S scores (i.e., PA-S and NA-S). The main effect of pre-post mock crime video was statistically significant on PA-S, $F(1,90) = 18.14$, $p < .001$, $\eta p^2 = .17$. More specifically, the initial positive state decreased after the video was shown for both low ($M_{\text{pre-mock crime}}$ = 25.74, 95% CI [23.77, 27.70] vs $M_{\text{post-mock crime}}$ = 24.02, 95% CI [21.80, 26.24]) and high EF resources individuals ($M_{\text{pre-mock crime}}$= 24.59, 95% CI [22.47, 26.70] vs $M_{\text{post-mock crime}}$ = 20.96, 95% CI [18.96, 22.95]). By contrast, the main effect of pre-post mock crime video on NA-S did not reach the statistical significance, $F(1,90) = 1.42$, $p = .24$, $\eta p^2 = .02$. Although there was no statistically relevant effect, the initial negative state appeared to increase for both low ($M_{\text{pre-mock crime}}$ = 7.37, 95% CI [4.62, 10.12] vs. $M_{post\text{-}mock\ crime}$ = 8.17, 95% CI [5.75, 10.60]) and high EF resource participants ($M_{pre\text{-}mock\ crime}$ = 5.26, 95% CI [3.38, 7.14] vs $M_{post\text{-}mock\ crime}$ = 5.76, 95% CI [3.79, 7.73]). These results suggest that the mock crime video statistically only affected the positive state of participants, while the increase of the negative state was not statistically significant.

Analysis on Cued Recall Scores

Memory scores (cued recall) were entered in three 2 (EF resources: low vs high) x 2 (memory test-retest: T1 vs T2) mixed ANOVAs, with EF resources as a between subjects factor and memory test-retest as a within subjects factor.

Regarding the correctness score, the main effects of EF and test-retest factors were statistically significant [$F(1,90) = 4.31$, $p = .04$, $\eta p^2 = .05$ and $F(1,90) = 23.69$, $p < .001$, $\eta p^2 = .21$, respectively]. The interaction effect of EF resources by test-retest was not significant [$F(1,90) = 1.98$, $p = .16$, $\eta p^2 = .02$]. Post hoc Bonferroni corrected comparisons demonstrated that high EF participants reported more correct details ($M_{T1} = .37$, 95% CI [.35, .39], $M_{T2} = .43$, 95% CI [.40, .46]) than low EF participants [$M_{T1} = .36$, 95% CI [.34, .38], $M_{T2} = .39$, 95% CI [.38, .41], $t(90) = 2.08$, $p = .04$, 95% CI [.001, .051], $d = .22$]. Moreover, both groups reported more correct details at T2 than T1 [$t(90) = -4.84$, $p < .001$, 95% CI [-.06, -.03], $d = -.51$].

Concerning the omissions score, both the main effects of EF and test-retest factors reached the statistical significance level [$F(1,90) = 5.36$, $p = .02$, $\eta p^2 = .06$ and $F(1,90) = 25.51$, $p < .001$, $\eta p^2 = .22$, respectively]. No significance was found for the interaction effect, $F(1,90) = .56$, $p = .46$, $\eta p^2 = .006$. Post hoc Bonferroni corrected comparisons confirmed that high EF participants reported fewer omissions ($M_{T1} = .38$, 95% CI [.34, .41], $M_{T2} = .33$, 95% CI [.29, .37]) than low EF participants [$M_{T1} = .43$, 95% CI [.40, .45], $M_{T2} = .36$, 95% CI [.34, .39], $t(90) = -2.32$, $p = .02$, 95% CI [-.08, -.006], $d = -.24$]. Moreover, both groups reported more omissions at T1 ($M = .40$, 95% CI [.38, .42] than T2 [$M = .35$, 95% CI [.32, .37]; $t(90) = 5.06$, $p < .001$, 95% CI [-.03, .08], $d = .53$].

Regarding the commission scores, the analysis revealed a significant main effect of test-retest and a statistically significant interaction effect of EF resources by test-retest [$F(1,90) = 880.289$, $p < .001$, $\eta p^2 = .91$ and $F(1,90) = 13.68$, $p < .001$, $\eta p^2 = .13$, respectively]. The main effect of the EF factor was found not significant, $F(1,90) = .11$, $p = .74$, $\eta p^2 = .001$. Post Hoc Bonferroni corrected comparisons demonstrated that high EF participants reported significantly more commissions at T2 ($M_{T2} = .56$, 95% CI [.53, .59]) than T1 [$M_{T1} = .25$, 95% CI [.22, .28], $t(90) = -18.36$, $p < .001$, 95% CI [-.35, -.26], $d = -1.92$]. The same was found for low EF participants who reported more commissions at T2 ($M_{T2} = .61$, 95% CI [.59, .62]) than T1 [$M_{T1} = .21$, 95% CI [.19, .23], $t(90) = -23.60$, $p < .001$, 95% CI [-.44, -.35], $d = -2.46$]. Finally, commission errors at T2 were statistically lower for high EF participants than for low EF participants [$t(90) = -2.80$, $p = .034$, 95% CI [-.09, -.002], $d = -0.29$]. No other differences between groups did reach the statistical significance (*ps* > .05).

---------insert Figure 1 about here-------

Analysis on Free Recall Scores

In line with analyses run on cued recall scores, three 2 (EF resources: low vs high) x 2 (memory test-retest: T1 vs T2) mixed ANOVAs, with EF resources as a between subjects factor, and memory test-retest as a within subjects factor were conducted on free recall scores.

With regard to the correctness scores, the main effects of EF resources and the interaction effect of EF by test-retest were statistically significant [$F(1,90) = 4.21$, $p = .04$, $\eta p^2 = .05$ and $F(1,90) = 4.17$, $p = .04$, $\eta p^2 = .04$, respectively]. The main effect of test-retest was not significant [$F(1,90) = 1.08$, $p = .30$, $\eta p^2 = .01$]. However, post hoc Bonferroni corrected comparisons confirmed only a statistically significant difference between high and low EF participants. In particular, high EF participants recalled more correct details ($M_{T1} = .16$, 95% CI [.14, .18], $M_{T2} = .16$, 95% CI [.15, .18]) than low EF participants [$M_{T1} = .15$, 95% CI [.13, .16], $M_{T2} = .13$, 95% CI

[.12, .15], $t(90) = 2.05$, $p = .04$, 95% CI [<.001, .047], $d = .21$]. No other differences of our interest (i.e., comparisons of interaction effect) were statistically significant (*ps* > .05).

Concerning the omissions scores, no significant effects were found for the EF factor, test-retest, and interaction [respectively, $F(1,90) = 2.65$, $p = .11$, $\eta p^2 = .03$, $F(1,90) = 0.65$, $p = .42$, $\eta p^2 = .007$, $F(1,90) = 2.71$, $p = .10$, $\eta p^2 = .03$].

Finally, the main effects of EF resources and interaction of EF by test-retest were statistically significant on the commission scores [$F(1,90) = 4.21$, $p = .04$, $\eta p^2 = .05$ and $F(1,90) = 4.17$, $p = .04$, $\eta p^2 = .04$, respectively]. The main effect of test-retest was not significant [$F(1,90) = 1.08$, $p = .30$, $\eta p^2 = .01$]. Post hoc Bonferroni corrected comparisons showed that high EF participants reported fewer commissions ($M_{T1} = .84$, 95% CI [.82, .86], $M_{T2} = .84$, 95% CI [.82, .85]) than low EF participants [$M_{T1} = .86$, 95% CI [.84, .87], $M_{T2} = .87$, 95% CI [.85, .88], $t(90) = -2.05$, $p = .04$, 95% CI [-.047, <.001], $d = -.21$]. Other differences of our interest (i.e., interaction comparisons of interaction effect) did not reach the statistical significance (*ps* > .05).

---------insert Figure 2 about here-------

---------insert Table 1 about here-------

Discussion

The present study was conducted to assess whether the individual availability of EF resources can influence memory accuracy for a crime. We aimed to address this goal by extracting participants with high vs low EF resources[6] from a large pool of people and asking them to watch a (mock) crime video imagining themselves to be an eyewitness. Then, participants' memory was assessed on two different occasions (test vs retest) through a cued and free recall. In line with previous studies that have demonstrated a higher likelihood of low EF individuals to report more memory distortions than high EF individuals (Gerrie & Garry, 2005; Jaschinski & Wentura, 2002;

Mirandola et al., 2015; Peters et al. 2007; Watson et al., 2005), results showed that EF resources affect the individual's memory for a crime.

First, our findings on correct details – both for cued and free recall scores – showed that high EF participants were more likely to report correct details than participants with low resources. What could be an explanation for these findings? By resuming the definitions of the EFs considered in our study (i.e., Updating, Shifting, and Inhibition) (e.g., Jonides & Smith, 1997; Logan, 1994; Lehto, 1996; Miyake et al., 200; Monsell, 1996), we could argue that people in the low EF group were those who were less able to switch between different details of an event, suppress interferences, and monitor and code relevant information. Such a lower ability might have affected their encoding of different details present in the mock crime video. This results in remembering fewer correct details than high EF participants. Surprisingly, our data on cued recall scores demonstrated that both groups (i.e., low and high EF participants) reported more correct details after ten days (retest) than immediately after the video presentation (test). These findings can be explained by taking into account the results of the analyses on the screening measures, showing that watching the crime video caused a change in participants' mood. Note that we did not include in our design a comparison between events with different valence (e.g., neutral vs. negative events) to evaluate the direct impact of the emotion triggered by the video exposition upon participants' memory for that video. Hence, our explanation might appear rather speculative, although supported by previous studies (e.g. Holland, Addis, & Kensinger, 2011; Levine & Edelstein, 2009) showing that the retrieval of event-related information can be negatively affected by a strong emotional impact and it improves in a second moment when such an impact becomes lower. In line with these studies, we can thus reasonably say that the affective impact of the crime displayed in the video negatively influenced the retrieval of details immediately after its presentation, while this effect was weakened at the retest session. Moreover, our findings are in line with previous studies on the phenomena of hypermnesia and reminiscence (e.g., Payne, 1987; Payne & Anastasi, 1991; Roediger & Thorpe, 1978; Scrivner & Safer, 1988). These studies have demonstrated -- by adopting repeated memory tests -- that people sometimes start to remember more details. Scholars have usually explained this pattern of results by arguing that repeated memory testing can play a facilitation role in recalling event-related information. This multiple testing permits people to retrieve initially not retrieved information in a subsequent moment (e.g., Scrivner & Safer, 1988). Despite these explanations, undoubtedly, future studies are needed to shed further light on our pattern of results.

Second, we also found an interesting pattern of results for memory errors. More specifically, our data on omission errors (i.e., details seen in the video but not reported in the recall) at the cued recall showed that high EF participants were less likely to omit details than low EF participants. The results are consistent with the above-mentioned findings on correct details scores. The low availability of resources of the low EF group resulted in a higher likelihood of not reporting information seen in the video. Moreover, and in line with findings on the correctness scores above discussed, our findings have demonstrated that, in general, omissions were higher at T1 than T2: When participants experienced emotional impact from the video shown them, they also reported less information in the immediacy than after ten days. However, these findings on omission errors were found only for the cued recall performance, whereas no significant results were found for the free recall.

With regards to commission errors (i.e., details distorted or completely wrong), our findings demonstrated that high EF participants scored lower than low EF participants only at T2, in the cued recall task. Moreover, when they were left to freely recall the event (i.e., free recall task), high EF participants reported fewer commission errors than low EF participants both at T1 and T2. Again, a possible explanation of this pattern of findings could be related to the role that EFs performed in human cognition. To illustrate, low EF individuals are less capable to suppress interferences and avoid reporting irrelevant information. Hence, when they recall an event, they have low availability of resources to reduce the confusion related to details seen and possible memory distortions (i.e., false memories) for specific parts of the event. This confusion makes such participants particularly prone to omit and report self-fabricated details. A parallel explanation was already proposed in previous studies on memory distortions and WMC (e.g., Gerrie & Garry; Leding, 2012; Peters et al., 2007; Unsworth & Brewer, 2010). In those studies, authors argued that having a poor ability to maintain relevant information and reduce interferences might render people susceptible to difficulties to retrieve the correct information. Due to problems in differentiating the encoded information from an imagined and automatically activated information, people report more memory distortions during the remembering of the event (Roediger, Watson, McDermott, & Gallo, 2001). Finally, both groups of participants reported more commissions at T2 than T1: Having experienced an emotional event protected participants from reporting distorted details or details never seen immediately after the video presentation, regardless of the availability of EFs resources. This latter finding is also in line with studies that have demonstrated that memory accuracy may decline with an increased level of delay between the encoding and retrieval of the information (e.g., Meisser, 2007; Shaw, Garven, & Wood, 1997). Hence, it could be that the delay has reduced the differences in cognition between groups and this resulted in an equal difficulty in avoiding to report commissions.

Some caveats of our study need to be pointed out. First, our participants were undergraduate students of the psychology faculty. This could limit the generalizability of our findings because the range of participants' age is rather limited. Previous studies have shown that executive functioning decreases with the increase of age (Souchay & Isingrini, 2004). Hence, it could be the case that in a sample with a higher range of age these findings will not be replicated.

Second, since we have found an emotional impact of the video on participants' state, another important point that needs more attention is understanding whether our findings can be due to the valence of the video. Hence, future studies need to include a manipulation of the video valence along and in interaction with the individual's availability of EF resources.

Third, we did not find the same pattern of results for the cued and free recall tasks in all memory scores. Further studies are required to systematically evaluate whether the individuals' availability of EF resources predicts memory accuracy for an event with respect to the kind of memory task employed.

Finally, in our study we considered an overall measure of the individual's EF resources. Indeed, following the idea that the three executive functions of Updating, Shifting and Inhibition are strongly related to each other and work together in the execution of complex cognitive processes, we divided our sample into high and low EF resources by considering the participants that reported the highest and lowest performance at all the three tasks. However, a next step could be to understand whether each executive function can play an independent role upon memory accuracy for a crime. Future studies could try to figure out this issue.

To sum up, in the current study, we have provided support to the idea that individual differences – in terms of EF abilities – can be associated with a better or worst memory accuracy for a crime. The results of our experiment could be relevant to the legal arena, and of utmost importance for legal professionals who have to rely on individuals' memory-related statements in legal proceedings. Indeed, our findings support the idea that assessing the individual characteristics in terms of EF resources can be helpful for the evaluation of eyewitnesses' reliability.

Notes

[1] Distortions caused purely by memory mechanisms without any suggestive pressure (e.g., Howe, Wimmer, Gagnon, & Plumpton, 2009).

[2] Working Memory is typically defined as the system implicated in the active maintenance and manipulation of information both during memory storage and retrieval from long-term store (e.g., Baddeley & Hitch, 1974; Engle & Kane, 2000; Kane & Engle, 2002).

[3] The choice to use a mock crime video is due to the intention to reproduce a real situations and is supported by studies that have shown that visual stimuli (e.g., video) are better remembered than verbal stimuli (e.g., words, narrative stories) because of their higher distinctiveness (Nelson et al., 1976) and the two levels of encoding (i.e., verbal and visual) (Paivio, 1976, 1986).

[4] We intentionally gained our sample for two reasons: (i) our sample could be susceptible to a high attrition rate since our design required the participation in two sessions with a large delay between each other and (ii) we subsequently selected participants with low and high EFs resources thereby creating our between-subjects factor. For such a new factor more participants were required.

[5] We have reported the descriptive statistics and the rank distributions in a supplemental materials file: https://osf.io/q7gj9/.

[6] We followed the Miyake and colleagues' model (2000) of executive functions and decided to assess the individuals' EFs resources by administering three executive tasks.

Disclosure statement

No potential conflict of interest was reported by the authors.

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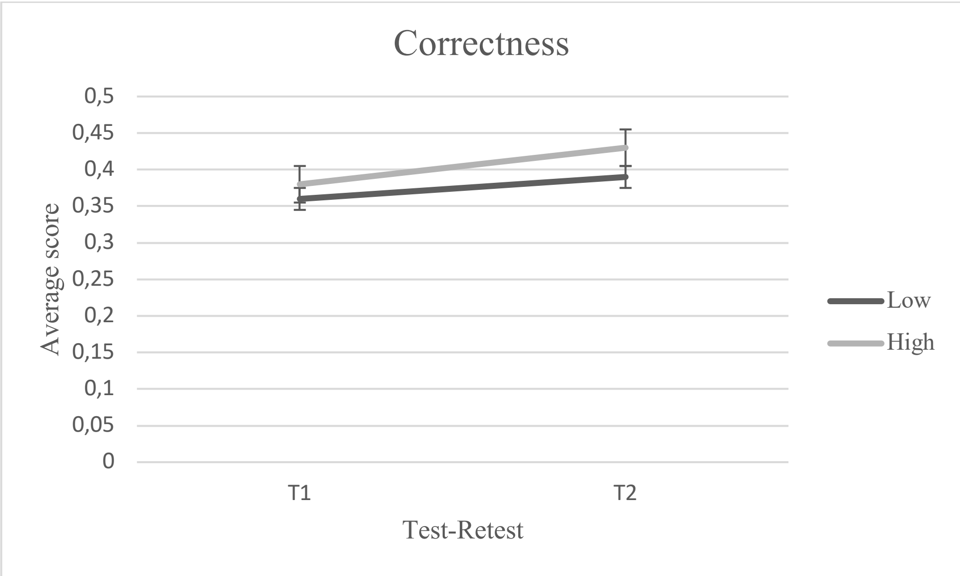
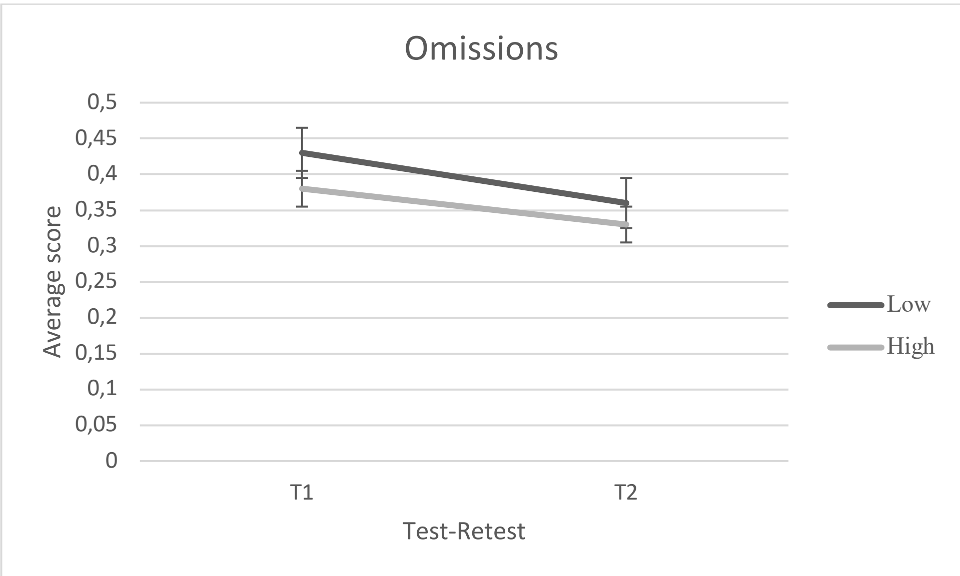
Memory scores	Low EFs		High EFs	
	T1	T2	T1	T2
Cued Recall				
Correctness	0.36(0.07)	0.39 (0.06)	0.38 (0.07)	0.43 (0.10)
	95% CI [.34, .38]	95% CI [.38, .41]	95% CI [.35, .39]	95% CI [.40, .46]
Omissions	0.43 (0.08)	0.36 (0.09)	0.38 (0.10)	0.33 (0.14)
	95% CI [.40, .45]	95% CI [.34, .49]	95% CI [.34, .41]	95% CI [.29, .37]
Commissions	0.21[a,b] (0.07)	0.61[a,c,d] (0.06)	0.25[d,e] (0.10)	0.56[b,c,e] (0.10)
	95% CI [.19, .23]	95% CI [.59, .62]	95% CI [.22, .28]	95% CI [.53, .59]
Free Recall				
Correctness	0.15 (0.06)	0.13 (0.05)	0.16 (0.07)	0.16 (0.06)
	95% CI [.13, .16]	95% CI [.12, .15]	95% CI [.14, .18]	95% CI [.15, .18]
Omissions	0.82 (0.07)	0.83 (0.06)	0.80 (0.08)	0.77 (0.09)
	95% CI [.79, .84]	95% CI [.81, .85]	95% CI [.78, .83]	95% CI [.80, .82]
Commissions	0.86 (0.06)	0.87 (0.05)	0.84 (0.07)	0.84 (0.06)
	95% CI [.84, .87]	95% CI [.85, .88]	95% CI [.82, .86]	95% CI [.82, .85]

Table 1. Mean proportions memory scores (i.e., cued recall scores and free recall scores) reported during the first (T1) and the second (T2) memory test by the two groups of low and high EFs resources. Standard deviations and 95% CI are shown between parentheses. Same letters display significant differences between groups at least at $p < .05$

a.


Correctness
0,5
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
Average score
T1
T2
Test-Retest
Low
High

b.


Omissions
0,5
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
Average score
T1
T2
Test-Retest
Low
High

c.

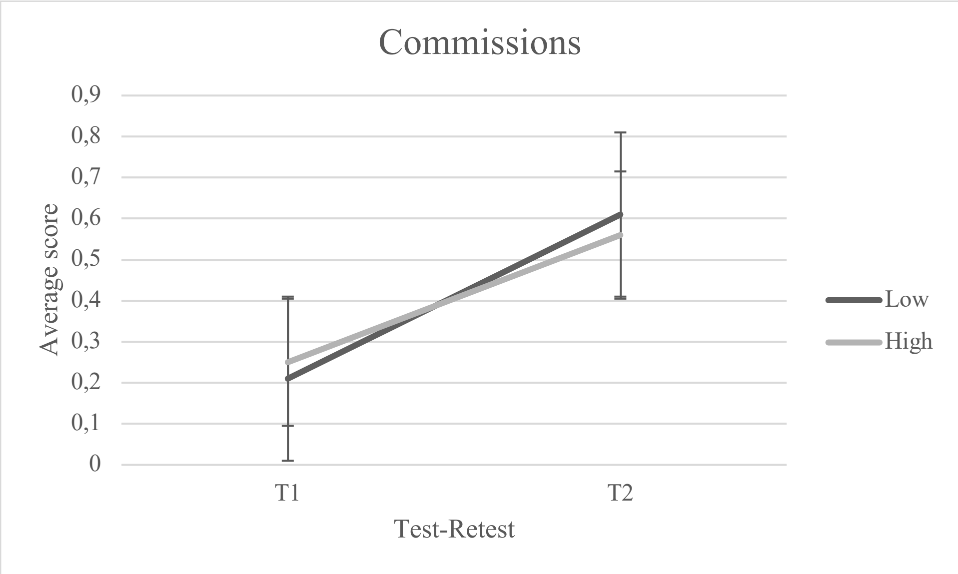
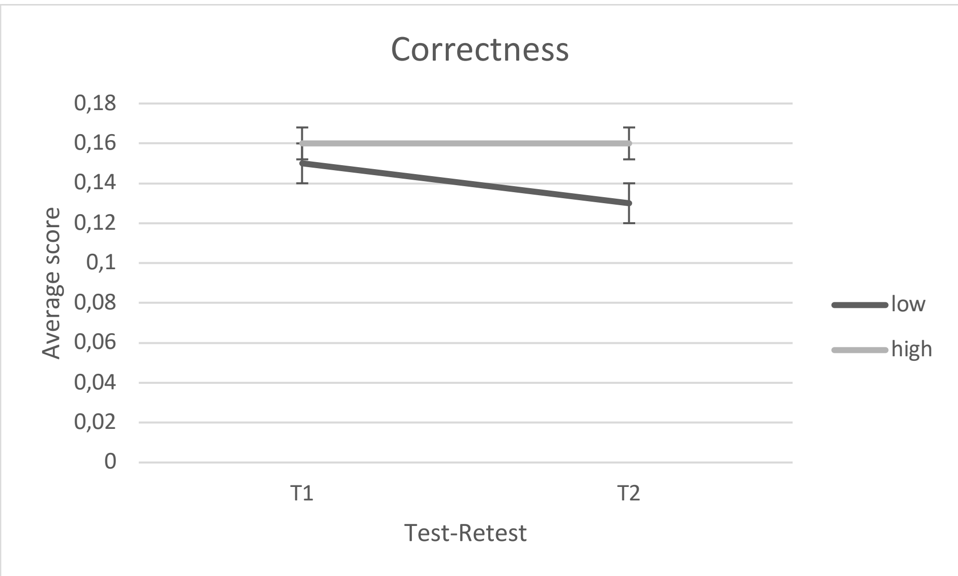
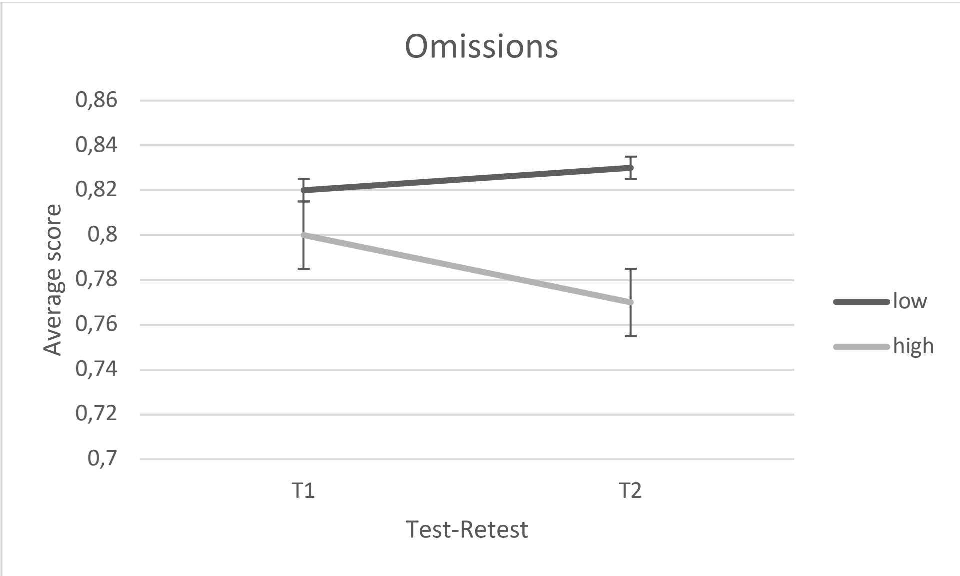


Figure 1 **a** Correctness scores reported by both the groups (i.e., low and high EFs abilities) at the two cued recall (T1 and T2). **b** Omissions scores reported by both the groups (i.e., low and high EFs abilities) at the two cued recall (T1 and T2). **c** Commissions scores reported by both the groups (i.e., low and high EFs abilities) at the two cued recall (T1 and T2). Error bars represent 95% confidence intervals.

a.



b.



c.

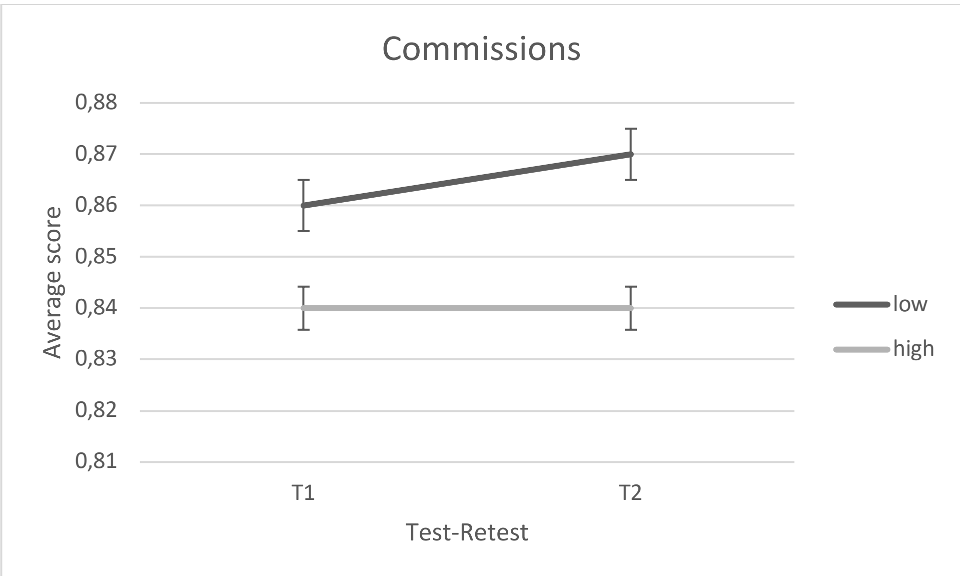


Figure 2 a Correctness scores reported by both the groups (i.e., low and high EFs abilities) at the two free recall (T1 and T2). **b** Omissions scores reported by both the groups (i.e., low and high EFs abilities) at the two free recall (T1 and T2). **c** Commissions scores reported by both the groups (i.e., low and high EFs abilities) at the two free recall (T1 and T2). Error bars represent 95% confidence intervals.