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COGNITIVE CONTROL ACROSS MULTIPLE DOMAINS: SEMANTIC CONFLICT, EMOTION, AND DISHONESTY

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Abstract

Cognitive control refers to the mental processes that enable individuals to manage their thoughts, emotions, and behaviors in pursuit of specific goals. This ability can involve overriding automatic or habitual responses, and adapting to new information (Diamond, 2013). The present thesis investigates how cognitive control is modulated in different conflict contexts: Semantic, emotional, and conflict arising from dishonest responses.

Our findings show that cognitive control – operationalized here as sequential modulation of interference – is activated during semantic interference and dishonest contexts, but not in response to emotional stimuli. In the semantic context, we employed a Picture Word Interference (PWI) task to study whether the repetition of superordinate categorical versus perceptual features affects cognitive control. Binding-retrieval accounts suggest that trial features that occur in the same time frame are bound together in an episodic representation. If a feature of episodic representation is repeated in the next trial, the previous control state is also reactivated (Frings et al., 2020). Our findings showed that the effect of the sensory/perceptual repetition did not add to the repetition of the category, suggesting that only the superordinate category feature is involved in episodic representation here. In a dishonest context, we employed a Reaction Time Concealed Information Test (RT-CIT), where participants categorized previously seen and new items as “old” or “new”. Participants were required to respond either truthfully or dishonestly. We observed slower responses in dishonest conditions compared to honest ones, suggesting conflict monitoring (Foerster et al., 2017, 2018, 2023). Moreover, responses following dishonest trials were faster than those following honest ones,

indicating that previously activated conflict monitoring led to better performance in subsequent trials. The interference from dishonest responses decreased in trials following dishonest conditions compared to those following honest conditions, suggesting a pattern similar to CSE. Contrary to semantic and dishonest contexts, a pattern of sequential dampening of interference was not observed when the interference was caused by the attentional capture of emotional scenes during a parity judgment task.

Overall, the research observes that cognitive control is activated in two different types of conflict. In our paradigm, semantic and dishonest conflicts may activate cognitive stability – a characteristic of cognitive control that enables individuals to maintain attention and adhere to a consistent approach despite distractions or competing information (Egner, 2023). We observed similar patterns in the activation of cognitive stability – a reduction in interference semantic conflict after incongruent trials, and a reduction in dishonest interference after dishonest responses. These results highlight the role of episodic representation, where the features of an event can be retrieved when a feature from a previous trial, encoded in an episodic representation, is presented in the next trial (Egner, 2023; Frings et al., 2020). The repetition of the previous conflict condition can reactivate the previous cognitive control, leading to better performance in subsequent trials (Egner, 2023; Frings et al., 2020). However, our results suggest that this pattern does not apply to all types of conflict. In the case of emotional distractors, the conflict could be more related to attentional capture than to response conflict.

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Introduction

What is cognitive control?

Imagine you are driving on a road you know very well, intending to reach a place you have never been before. To get there, you will need to take a turn you have never taken before by following the directions from your GPS. What would happen if you got distracted and did not follow the GPS instructions? You would probably continue on the familiar route, missing the turn. If this happens, you can blame your cognitive control for not doing its job properly! Cognitive control refers to the mental processes that allow individuals to regulate their thoughts, emotions, and actions in a goal-directed manner. It involves overriding automatic or habitual responses, adapting to new information, and managing attention to achieve desired outcomes (Diamond, 2013).

In the literature, attempts have been made to identify the main modalities through which cognitive control is enacted. For example, the Dual Mechanisms of Control model (DMC; Braver, 2012; Braver et al., 2007) outlines two main mechanisms of cognitive control: proactive and reactive controls. Proactive control involves the anticipatory activation of goal-related cognitive representations, driven by the dopamine system. Reactive control, on the other hand, is characterized by short-lived, stimulus-driven activation of goals. This mechanism is influenced by neural circuits responsible for interference or conflict detection and episodic/associative cueing. Another relevant distinction is between cognitive flexibility and stability, describing them as key characteristics of cognitive control (Egner, 2023; Geddert and Egner, 2022). Cognitive stability is the ability to maintain the focus on relevant information while ignoring the distractors, and cognitive flexibility is the ability to switch the focus from one task to another. Although cognitive stability and cognitive flexibility reflect two distinct characteristics that manage cognitive control, they are both regulated by the same two learning principles, which refer to current demands and past experiences (Egner, 2023). The first learning principle is related to how cognitive control is adjusted based on current demands. This principle represents a proactive, anticipatory, and real-time learning process. For instance, depending on what you are doing or what your environment requires at a given moment, this process helps you adjust the level of stability (e.g., maintaining focus on the task set) or flexibility (i.e., adapting by changing your focus) in your action. The second learning principle deals with how past experiences - specifically episodic memory - were used to guide cognitive control. This principle is about remembering previous situations and the control strategies that were used. When you encounter a similar previous context, you can recall the cognitive control settings you used before. Moreover, the ability to maintain task focus (i.e., stability) and the ability to switch tasks (i.e., flexibility) are considered to operate at different levels within the hierarchy of working memory. Task focus is responsible for maintaining the task set active in working memory. On the contrary, the task-switching process is responsible for selecting task sets into working memory. Hence, stability and flexibility are considered two opposing processes along a continuum of states.

The present research focuses on cognitive stability, aiming to study how this mechanism can modulate cognitive control during different conflict conditions while maintaining the same task set.

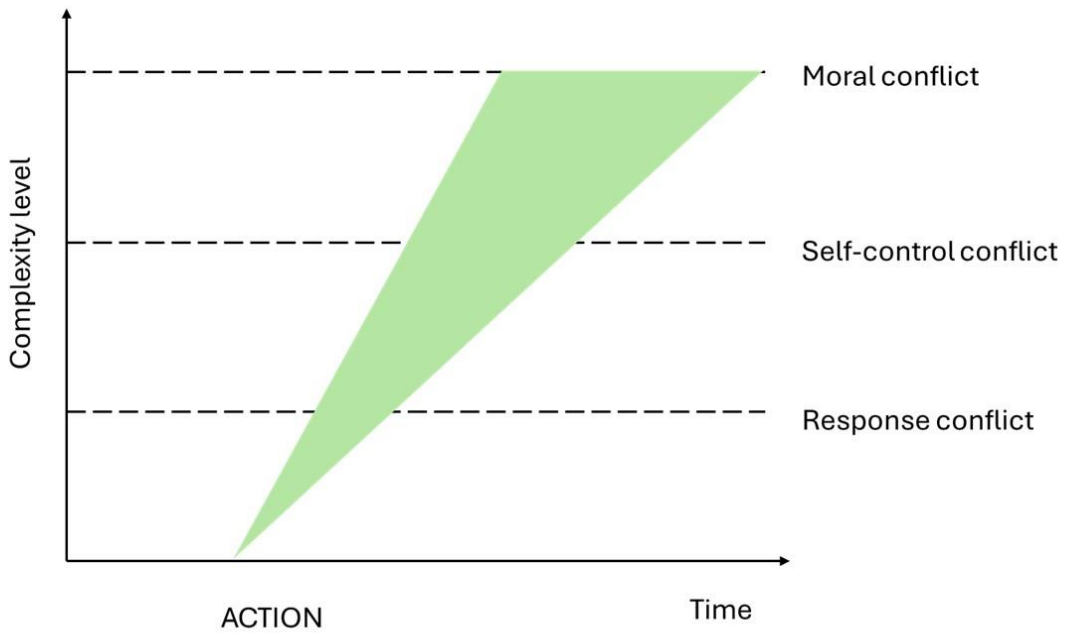
Multiple domains of conflict

Interference resolution is a fundamental aspect of cognitive control, involving the ability to prioritize task-relevant information, even when it competes with stronger, more habitual, and irrelevant cues (Miller and Cohen, 2001).

The process of conflict resolution has been conceptualized as a two-step process: Detecting the conflict and exerting control (Becker et al. 2024; Botvinick, 2001; Myrseth and Fishbach, 2009; Verguts and Notebaert, 2008). Becker et al. (2024) proposed an integrative model for understanding conflict and cognitive control across different domains. The model assumes that action and goal representations are organized hierarchically, as shown in Figure 1. At the bottom of the hierarchy, there are concrete actions that refer to response conflict and require inhibition of automatic responses (e.g., the Stroop task). At the top of the hierarchy, there are abstract goals such as moral conflicts and self-control conflicts. In the laboratory, an example of moral conflict is the trolley dilemma, where participants are asked to imagine a trolley running out of control on a track with five people tied to the rails, unable to move. If the trolley continues on its path, it will kill the five people. However, there is a lever that can divert the trolley to another track where only one person is tied, and participants are asked if they would pull the lever, knowing that doing so would kill one person to save the five. In a self-control conflict task, the conflict can arise from the desire to choose pizza versus the goal of staying healthy (Becker et al., 2024). Conflicts between abstract goals are more complex and take more time to resolve compared to those based on concrete conflicts. However, the model suggests that actions serve as the core of all conflicts. Even in abstract situations, decisions about actions are involved, and resolving these conflicts ultimately leads to tangible outcomes (Becker et al., 2024).

Figure 1

Hierarchy of conflicts



Note. The graph is based on the figure from the article by Becker et al. (2024) on the hierarchy of conflicts. Higher-level conflicts occupy a larger action space compared to lower-level conflicts. Additionally, conflicts at more abstract levels are also associated with a more prolonged temporal space for conflict regulation and a different onset of action compared to conflicts at lower levels.

In laboratory settings, some cognitive tasks have studied cognitive control during response conflict resolution, requiring participants to respond to task-relevant features (targets), ignoring task-irrelevant features (distractors) that have habitual response associations, and which can be either congruent or incongruent with the target-response (Cohen, 2017). For example, in the Stroop task (Stroop, 1935), participants have to name the ink color of colored words, ignoring the meaning of the word that can be congruent with the ink color (e.g., the colored word “blue” in blue ink) or incongruent (e.g., the colored word “blue” in red ink). The canonical results show slower responses to the incongruent trials compared to the congruent ones; this phenomenon is known as the semantic interference effect (Stroop, 1935), which is also observed in Picture-Word Interference (PWI) task (Rosinski, 1977). The PWI paradigm is a modified version of the Stroop task where images are used as targets and words appear alongside the images as distractors.

Other paradigms that involve conflict include the Eriksen-Flanker task (Eriksen and Eriksen, 1974), the Simon task (Simon and Berbaum, 1990), and the Multi-Source Interference Task (MSIT, Bush and Shin, 2006). In the Eriksen-Flanker task, a target stimulus is presented with distractors on both sides. Participants are required to respond to the central target while ignoring the surrounding distractors, which can be associated with the same response as the target (i.e., congruent condition) or differ from it (i.e., incongruent condition). The Simon task involves spatial conflict. Participants have to respond to a non-spatial attribute of the stimulus (e.g., stimulus shape), while the stimulus may appear on the same side as the button to press to respond (i.e., congruent trials) or on the opposite side (i.e., incongruent trials). The MSIT task presents three numbers (ranging from 0 to 3), with one number (the target) differing from the other two (the distractors). Participants are required to identify the target number, which can either be congruent or incongruent with its position (e.g., "121" for the congruent condition and "200" for the incongruent condition).

The common feature across all these tasks is the longer reaction times (RTs) for stimuli involving conflict compared to conflict-free stimuli. However, neural responses can differ depending on the task. For instance, a study by Xiao et al. (2023) found that most neural responses were task-specific since the left orbitofrontal cortex showed modulation due to the conflict in the high-gamma band only during the Stroop task. This suggests that electrocortical conflict modulation may vary by task, raising the question of how many types of conflict exist and whether cognitive control operates consistently across tasks. On the one hand, it might seem intuitive to argue that different tasks generate distinct types of conflict, although these conflicts may share a common underlying structure: The need to resolve the conflict due to the incongruence (Becker et al., 2024). Namely, to respond accurately to the task, it is necessary to inhibit the automatic response triggered by the distractor, which is incongruent with the required response and creates a conflict between the automatic response and the one needed. However, conflict resolution for different tasks may occur in various ways. This perspective is further supported by Paap et al. (2020), who highlighted the insufficient convergence between interference task scores. Specifically, the authors note that scores from different interference tasks fail to correlate with other measures designed to assess cognitive control.

The present research is focused on three different contexts that result in behavioral interference. The first context addresses semantic interference during a Picture Word Interference (PWI) task, where participants are asked to name the subject of a picture while ignoring the word presented alongside it. The distractor word can either be congruent (e.g., a picture of an animal with the word "animal") or incongruent (e.g., a picture of an animal with the word "vehicle") with the correct response (Rosinski, 1977). Semantic interference occurs since the meaning of distractor words affects the speed and/or accuracy of responding to the target images. When a word is presented alongside an image, if the word is incongruent, it may slow down the response or lead to errors, as the tendency to read the meaning of the word leads to the interference effect. Therefore, to provide the correct response, it is necessary to inhibit the response that might be generated by reading the word (Rosinski, 1977).

The second behavioral interference studied in the current project is the interference caused by emotional distractors. Emotional interference refers to the impact that emotionally charged stimuli can have on an ongoing cognitive task, impairing performance. When individuals are exposed to emotional distractor stimuli - whether positive or negative - while performing a cognitive task, their ability to focus may be compromised due to the emotional content, especially when compared to situations involving neutral distractor stimuli (Bradley et al., 1996, 1999; Calvo and Nummenmaa, 2007; Okon-Singer et al., 2007). This effect occurs since emotional stimuli tend to capture attention more effectively than neutral ones, redirecting attentional resources away from the task. The emotional nature of the stimuli may shift priorities, making it more difficult to process task-relevant information, due to the survival relevance of emotional stimuli (Anderson, 2018; Dolan, 2002). To respond to the task and adhere to instructions, it becomes necessary to inhibit emotional information. Thus, emotional interference arises from a conflict between the attentional capture generated by emotional stimuli and the task instructions. This can manifest as slower response times during the conflict conditions, compared to when no such conflict is present, similar to the effects seen during semantic interference.

The last type of response conflict studied in the present project is due to dishonest responses. The conflict created by lies arises when individuals are required to generate or maintain false information, suppressing the tendency to respond honestly (Duran et al., 2010; Walczyk et al., 2003; Foerster et al., 2023). Foerster et al. (2017), suggest that when individuals engage in deception, they must manage multiple aspects of the lie - such as remembering details, ensuring consistency, and monitoring reactions - while also suppressing the discomfort associated with the act of deceiving. The result is a higher cognitive load that interferes with performance on tasks. The interference caused by lies could be observed as slower responses during the dishonest condition compared to the honest condition (Verschuere, 2013; Suchotzki et al., 2017; Verschuere et al., 2010; klein Selle et al., 2023; Foerster et al., 2017, 2018, 2019, 2023), as seen during semantic conflict and the interference created by the attentional capture of emotional stimuli.

The behavioral responses due to the conflict appear to be similar across different types of conflict; however, the cognitive control activation resulting from different conflicts remains unclear.

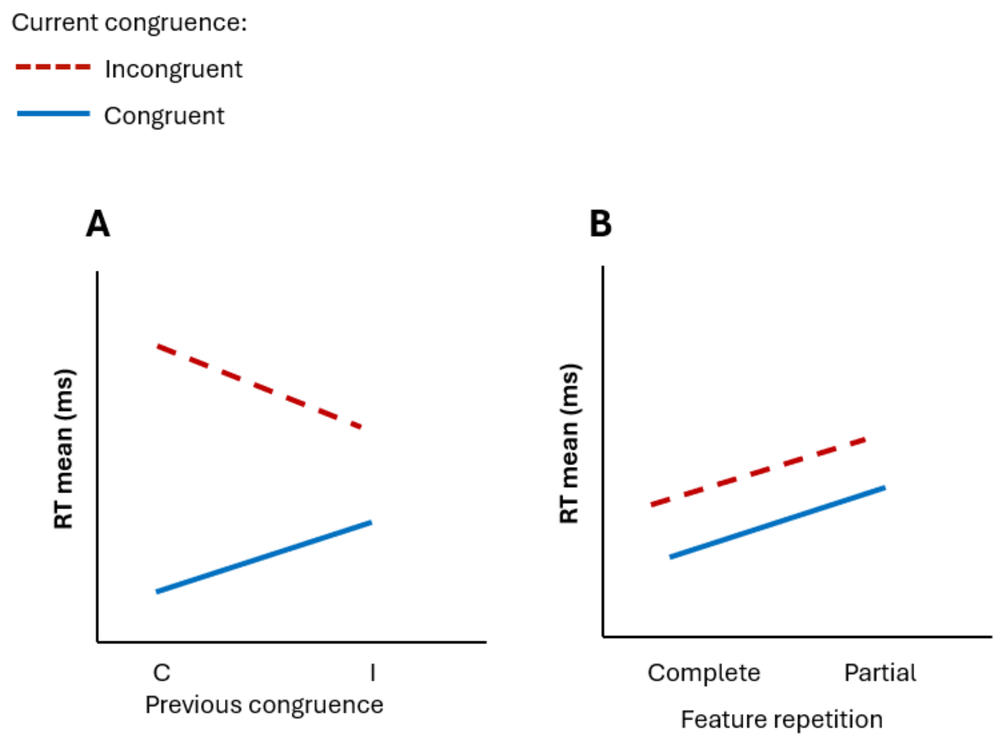
Is cognitive control activated only by conflict? Exploring cognitive control through the Congruence Sequential Effect

The interference effect due to incongruency can be influenced by the conflict in the previous trial. Notably, interference can be reduced if the previous trial is incongruent rather than congruent. This phenomenon is known as the Congruence Sequence Effect (CSE; Gratton et al., 1992), and it can be studied as a behavioral index of cognitive control.

Previous models that studied the mechanisms underlying the CSE can be classified into two main categories: top-down control-based accounts and bottom-up associative accounts. A well-known example of a top-down control-based account is proposed by Botvinick et al. (2001), who refer to the CSE as “conflict adaptation.” According to this model, when incongruent distractors create conflict, cognitive control is activated to enhance focus on the target, resulting in more efficient attentional selection in subsequent trials and, consequently, a smaller interference effect (Figure 2, panel A). On the other hand, when congruent distractors are encountered, lower conflict may lead to less efficient attentional selection, causing a larger interference effect in the following trial (Figure 2, panel A). This model suggests that the CSE arises from strategic adjustments in top-down attention. As a result, the level of abstraction of the mechanism can account for the occurrence of the CSE. Associative accounts suggest that the CSE may emerge from bottom-up effects, driven by the association between stimuli and responses (Hommel et al., 2004). According to this perspective, repeating the stimulus from a previous trial can influence the response in the following trial. During a trial, the stimulus and the corresponding response become bound together in episodic memory as an "event file" (Hommel, 1998, 2004). The retrieval of the previous stimulus can facilitate the response in the current trial if all features of the stimulus from the previous trial are repeated (i.e., complete repetitions), as the entire event file is recalled. Similarly, if there is no overlap between the current and previous trial features (i.e., complete alterations), the response is generated from scratch leading to a facilitation of the response. However, when only some of the features are repeated (i.e., partial repetition), response facilitation does not occur, because the event file must be "unbound" to allow for the correct response in the current trial. For example, in tasks such as Stroop or PWI, trial sequences like congruent-congruent or incongruent-incongruent (i.e., complete repetition), are associated with faster responses compared to trial sequences like congruent-incongruent or incongruent-congruent (i.e., partial repetition) (Figure 2, panel B).

Figure 2

Simulated data illustrating different interpretations of the CSE in Egner (2014)

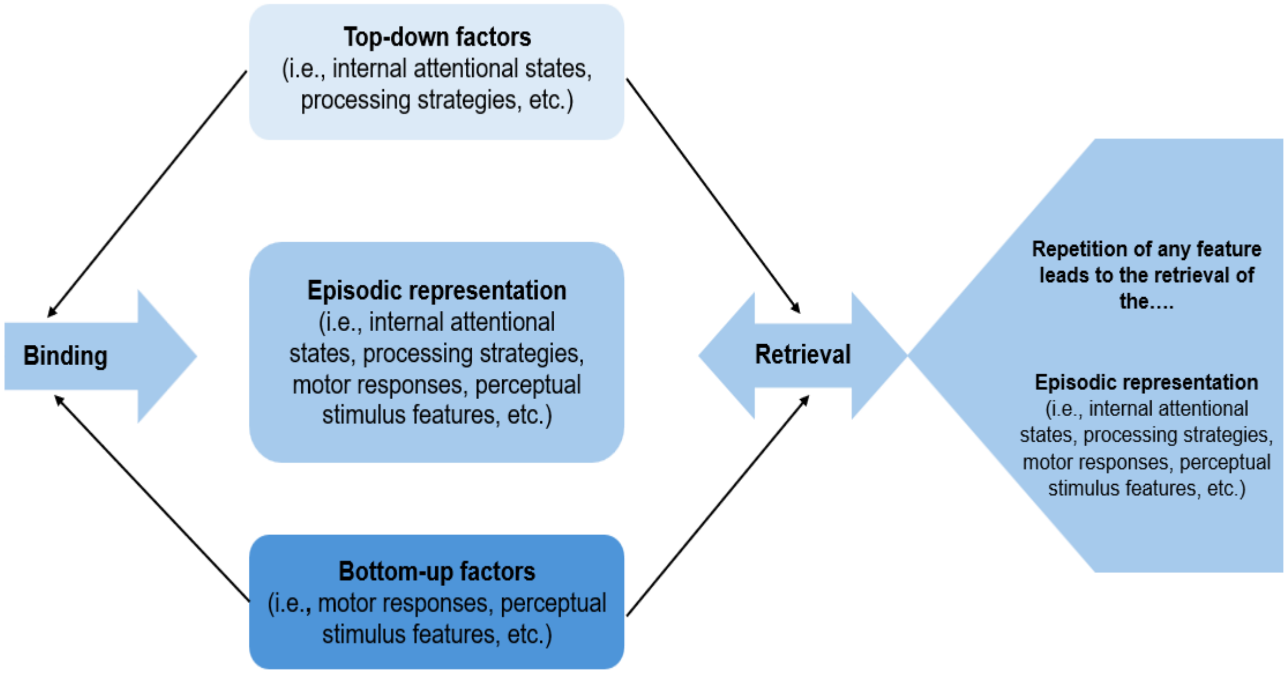


Note. (A) Response time (RT) varies based on the interaction between the congruency of the previous and current trials, as explained by the top-down control-based account. "C" indicates the previous congruent trial, while "I" indicates the previous incongruent trial. (B) The same simulated data from (A) is presented according to associative accounts. "Complete" refers to full feature repetitions or alterations from the previous trial, while "Partial" indicates partial feature repetitions from the previous trial.

Recent models attempting to integrate the ‘associative’ and ‘control-based’ highlight the role of learning to link external stimulation to appropriate internal states (Egner, 2014; Abrahamse et al., 2016; Dignath et al., 2019; Verguts and Notebaert, 2008). At the most concrete level, the motor response and the perceptual/sensory stimulus features that occur in the same trial can be bound in an episodic representation. At a higher level of abstraction, there could be a binding contextual cue to internal attentional states and processing strategies. Moreover, the Binding and Retrieval in Action Control model (BRAC; Frings et al., 2020) emphasizes that binding and retrieval are independent processes influenced by both top-down and bottom-up factors, as shown in Figure 3. The BRAC model tries to explain how past actions affect current behavior through the retrieval of previously bound features. When a feature of the episodic representation is repeated, other associated features can be retrieved, leading to the reactivation of the previous control state (Egner, 2023). This reactivation results in a more pronounced CSE compared to trials where no control state is reactivated (Frings et al., 2020; Egner, 2014). According to the BRAC model, traces in the episodic representation - such as perceptual/sensory features, responses, and the control states activated during the response (i.e., both low- and high-level) - can be treated interchangeably, influencing the CSE (Frings et al., 2020).

Figure 3

Modified representation of the Binding and Retrieval in Action Control model (BRAC) framework (Frings et al., 2020)



Note. The model proposes that binding and retrieval processes occur separately and are independently influenced by both top-down and bottom-up factors. Top-down factors are related to high-level features of a trial, while bottom-up factors involve low-level features. When these features occur within the same time frame, they are stored together in an episodic representation, which is then retrieved if any of the features are repeated in the future.

Research question

The present thesis aims to study in which conflict context cognitive control occurs and how it is modulated after the conflicting event has occurred.

The first chapter focuses on how cognitive control can counteract semantic interference and which repeated features of the episodic representation (e.g., superordinate category or perceptual/sensory features) can modulate cognitive control at both behavioral and electrocortical levels.

The second chapter investigates whether cognitive control can reduce emotional interference, similar to what has been observed during semantic conflict (i.e., the Congruence Sequence Effect - CSE). It also studied whether the reduction in interference is influenced by the repetition of the episodic representation, specifically the repetition of a sensory-level characteristic (blurriness) of the image.

In the last chapter, cognitive control is studied during the production of dishonest responses to understand whether the previous deception monitoring can affect the following event, even after the execution of the dishonest response itself.

Chapter 1: Binding and retrieval in cognitive control during semantic conflict

1.1 Which repeated features of a stimulus can influence cognitive control?

The Binding and Retrieval in Action Control (BRAC) model, proposed by Frings et al. (2020), suggests that features occurring within the same temporal window are integrated into an episodic representation. The processes of binding and retrieval are distinct and shaped by both top-down and bottom-up influences. When one element from an episodic representation is repeated, its associated elements can be retrieved, leading to the reactivation of those elements within the episodic representation. The retrieval of elements of the episodic representation may involve the control states (e.g., heightened attentional selectivity; Chiu et al., 2017), which were previously engaged during previous conflict conditions. This reactivation can enhance performance in the current conflict situation, resulting in a stronger CSE (Congruency Sequence Effect) when features are repeated compared to conditions where no control state is reactivated (Frings et al., 2020; Egner, 2014). According to the model, the repetition of any component within an episodic representation - whether perceptual/sensory features, responses, or control states involved in the previous response - can trigger the reactivation of the previous control state.

Previous research has studied which repeated stimulus features might influence the CSE. For example, some studies found that the CSE was more pronounced when the modality of stimulus presentation (visual or auditory) was repeated, compared to when it alternated (Kreutzfeldt et al., 2016; Yang et al., 2017- Exp1A, 3A, Grant et al., 2020; Grant and Weissman, 2023). Kelber et al. (2023) also observed in their first experiment that repetition of the modality (visual or auditory) of trial presentation led to greater CSE compared to when the modality changed. In the second study by Kelber et al. (2023), the authors observed greater CSE when the intensity of stimuli (i.e., brightness and loudness) was repeated. Moreover, Schiltenwolf et al. (2024) found a greater CSE when the characteristics of the numerical stimulus (i.e., digits or words) were repeated in the first four experiments. In the final experiment, this pattern was observed when the numerical stimulus and the response, as well as the brightness of the stimulus, were repeated, rather than when they changed. Dignath et al. (2021) found that cognitive control is enhanced when the sequence of a prime and target is consistent across trials. For example, if the previous trial presented a prime followed by a target (prime → target) and the current trial followed the same order (prime → target), participants showed a stronger cognitive control effect (CSE). In contrast, when the order changed – if the previous trial was prime → target and the current trial switched to target → prime – the cognitive control effect was weaker. This suggests that consistency in the order of stimuli improves cognitive processing and performance. Similarly, Spapè and Hommel (2008) observed a similar pattern when the gender of a task-irrelevant voice was repeated across trials. Recent studies have reported a stronger CSE when the formats of the target and distractor were repeated across trials (Dignath and Kiesel, 2021; Dignath et al., 2019). Taking together, these results suggest that the repetition of features that are common to several stimuli (e.g., modality, sequence, superordinate features) may modulate CSE. More recently, in a study by De Cesarei et al. (2023), a larger CSE was observed when the same stimuli -natural images- repeated during a categorization task, compared to when stimuli changed; this suggests that the features belonging to an individual stimulus can be stored in episodic memory and retrieved in subsequent trials. However, since changes in image identity also involved shifts in the category, it is unclear whether the reactivation of episodic representations was driven by the repetition of the superordinate category (i.e., features that are shared among different stimuli) or by the repetition of the perceptual/sensory features of the image (i.e., features belonging to an individual stimulus).

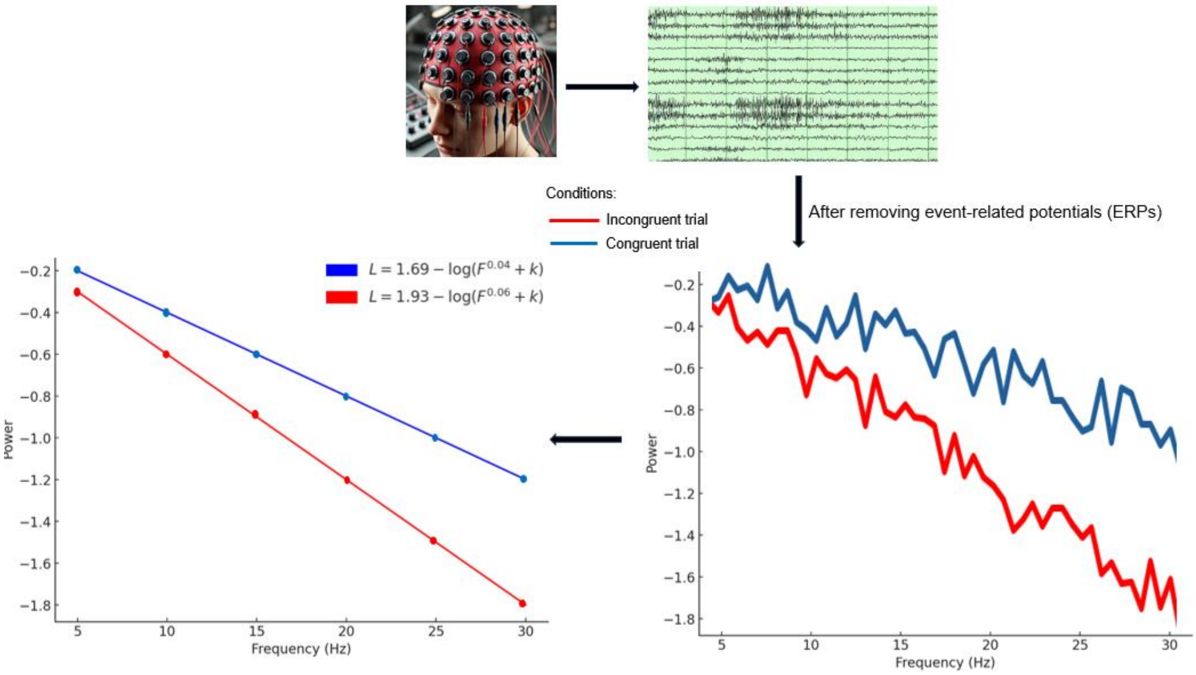
Therefore, which repeated features of the previous trial can reactivate cognitive control from the episodic representation? Only features that are shared among different stimuli of the stimulus, or also features belonging to an individual stimulus?

1.2 Electrocortical index of cognitive control

Oscillatory activity could reflect higher-level cognitive functions and has been analyzed using electrophysiological methods, such as electroencephalogram (EEG; Ward, 2003; Fries, 2005; Beste et al., 2023). Oscillatory activity refers to the rhythmic neural signals. Neurons communicate with one another by transmitting electrical impulses. When a neuron activates, it produces an electrical signal that travels down its axon, leading to the release of neurotransmitters at synapses and facilitating communication with nearby neurons. These electrical impulses give rise to oscillations - patterns of repeated fluctuations in neural activity (Cohen, 2014). Oscillations represent the synchronization of groups of neurons and can be detected as rhythmic waves of electrical activity. These patterns are classified into various frequency bands, such as delta, theta, alpha, beta, and gamma, and each can be linked to specific cognitive functions and states of consciousness (Cohen, 2014). Frequency indicates how fast the oscillations occur, measured in Hertz (Hz), representing the number of cycles per second. It defines the speed at which these electrical patterns repeat and is inversely related to time. Another characteristic of the oscillatory activity is the power, which measures the strength or intensity of the oscillation within a specific frequency range. It reflects the squared amplitude of the oscillation, often expressed in microvolts squared (μV^2), representing the energy in that frequency band (Cohen, 2014). An electrocortical index of cognitive control could be found in the aperiodic components (Pi et al., 2023; Jia et al., 2024; Lu et al., 2024; Zhang et al., 2024). The aperiodic component, commonly referred to as noise activity or "scale-free" broadband activity, is described by a 1/f^x function, where the exponent "x" defines the steepness of the power decrease across different frequencies (Donoghue et al., 2020). The main parameters of the aperiodic components are exponent (1/f slope) and offset (i.e., a parameter that reflects the uniform shift of power across frequencies). Changes in the slope, which correspond to shifts in the exponent, can be visualized as rotations in the log-log power spectrum: A clockwise rotation indicates a more negative value or steeper spectrum, while a counterclockwise rotation suggests a less negative value or flatter spectrum (Kamala et al., 2023), as shown in Figure 4.

Figure 4

An example of how EEG analyses of the exponent component from raw EEG data are calculated



Note. The experimental conditions considered were the congruence of the current trial, and regressions were computed based on five frequency bands. At the top, the two functions represent the regressions of the simulated data, with the coefficients of x defining the slope. In the case of incongruent trials, a steep slope is observed, while a flatter slope is observed for congruent trials.

Recent studies have demonstrated a steeper 1/f slope (i.e., increased exponent) during the controlled inhibition of a prepotent response (Pertermann et al., 2019a, 2019b). Then, steeper slopes are thought to reflect increased inhibition within the synaptic circuits, while flatter slopes may indicate greater excitation (Brake et al., 2024). This suggests that the 1/f slope in EEG signals could serve as an index of the balance between excitatory and inhibitory synaptic circuits. The aperiodic activity could play a key role in understanding how the brain dynamically adapts its processing in high-level cognitive functions.

Zhang et al. (2023) studied whether the broadband aperiodic activity in the EEG power spectrum is associated with high-level cognitive functions in a Simon Go/NoGo task. The results showed a higher aperiodic exponent in the NoGo condition than in the Go condition, and during incongruent trials than in congruent trials only in the Go condition. Their results suggest that aperiodic activity could reflect the activation of cognitive control since the NoGo and incongruent trials (i.e., conflict conditions) induced greater response conflict than Go trials and congruent trials (i.e., no conflict conditions). The present findings suggest an inhibition of synaptic circuits during conflict conditions, while an excitation of synaptic circuits during conditions that do not involve conflict. Moreover, Jia et al. (2024) studied the effect of the conflict on the next trials. They observed that the higher aperiodic exponent in current incongruent trials did not lead participants to make fewer errors in the current trial but in the following one.

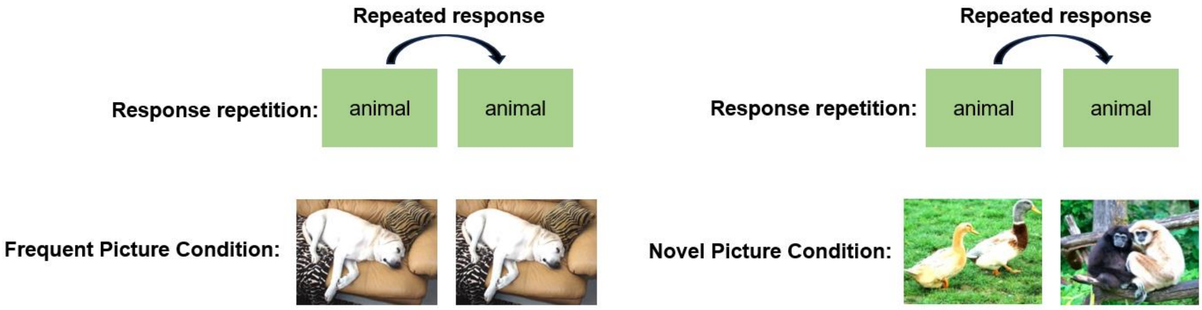
Therefore, the studies by Zhang et al. (2023) and Jia et al. (2024) support the idea that conflict can modulate aperiodic oscillations, which could be considered a physiological index of cognitive control. Since both conflict adaptation – driven by top-down mechanisms activated by the conflict condition (Botvinik et al., 2001) – and binding-retrieval processes –where the repetition of a feature stimulus can retrieve previous control (Frings et al., 2020) – are involved in conflict resolution, we investigated whether aperiodic oscillations reflect binding-retrieval processes, along with the influence of conflict adaptation, as observed in behavioral studies (Frings et al., 2020; Kreutzfeldt et al., 2016; Yang et al., 2017- Exp1A, 3A; Grant et al., 2020; Grant and Weissman, 2023, Kelber et al., 2023; Schiltenwolf et al., 2024; Dignath et al., 2021; Spapè and Hommel, 2008; Dignath and Kiesel, 2021; Dignath et al., 2019).

1.3 Research questions and hypotheses

The first chapter aims to investigate whether cognitive control is modulated by the repetition of features shared with other trials (i.e., superordinate category of the stimulus), or by details unique to the trial, such as the identity of the picture (i.e., perceptual/sensory stimulus features) from episodic representation, at both the behavioral level (Experiment 1) and the electrocortical level (Experiment 2). To this end, participants categorized natural scenes in a picture-word interference (PWI) task. Each picture was presented along with a verbal label that could be either congruent or incongruent with the response category (e.g., a scene of two animals with the “two” label was a congruent trial; an animal picture with the “vehicle” label was an incongruent trial; etc.). In one condition, the pictures were repeated across trials, so that a response repetition from one trial to another also implied the repetition of the same image (identity repetition), as in Figure 5. In the other condition, the pictures were all different, so the response repetition only implied the repetition of the same response category, like in Figure 5.

Figure 5

Example of two consecutive trials during the repetition of the response, in the two picture sets



If the episodic representation involves the binding and retrieval of the specific picture identity (i.e., perceptual/sensory features) from episodic representation, a larger CSE can be observed in repetition trials in the same image condition, compared to different, pictures. On the other hand, if the episodic representations involve only the response category, we can observe no differences between the two picture conditions in the modulation of the CSE by repetition, and a larger CSE during the repetition of the response category compared to when it changed.

Regarding the aperiodic component, higher exponents were observed during conflict conditions, suggesting the inhibition of synaptic circuits (Zhang et al., 2023). In the study by Jia et al. (2024), the inhibition of synaptic circuits observed during incongruent trials led to a reduced tendency to make errors in the next trials but not in the current trials. The authors suggested that the control adjustment is activated during a conflict situation and the activation will modulate the response in the next trial. In the EEG experiment, we asked whether the modulation of aperiodic component by the previous interference – the reduction in the difference of the aperiodic exponent between incongruent and congruent trials after incongruent trials compared to congruent ones; CSE – is influenced solely by the previous conflict experienced (Botvinick et al., 2001; Jia et al., 2024) or if it also reflects the binding-retrieval process that operates within the episodic representation (Frings et al., 2020). If the aperiodic CSE is not modulated by the repetition of the stimulus features, but by conflict only (Botvinick et al., 2001), we expect not to observe any modulation due to the trial repetitions. On the other hand, if aperiodic CSE is modulated by the repetition of the context, we can observe a larger CSE during the repeated context compared to when it changed. If this is the case, the next step is to understand which specific feature of the context modulates aperiodic CSE. If, as in behavioral studies (Kreutzfeldt et al., 2016; Yang et al., 2017- Exp1A, 3A; Grant et al., 2020; Grant and Weissman, 2023, Kelber et al., 2023; Schiltenwolf et al., 2024; Dignath et al., 2021; Spapè and Hommel, 2008; Dignath and Kiesel, 2021; Dignath et al., 2019), the aperiodic CSE is modulated by features that are shared among several stimuli of the stimulus (here, superordinate category), we should observe greater CSE during response repetition compared to when the response changes. On the other hand, if there is a modulation by the identity of the picture (i.e., perceptual/sensory feature), greater CSE should be observed during image repetition compared to when the images change.

1.4 Experiment 1 – Behavioral CSE during the trial repetition

1.4.1 Method

1.4.1.1 Participants

Eighty-two participants took part in the experiment, but two participants were excluded from the analyses due to low accuracy (53 females, age M= 23.49, SD= 4.03). All participants were fluent Italian-speaking with normal or corrected vision. The experimental protocol conformed to the declaration of Helsinki and was approved by the Ethical Committee of the University of Bologna. A power analysis was performed in R (using the pwrss package; Bulus, 2023) to estimate the necessary sample size for detecting the four-way interaction of interest (Current Congruency x Previous Congruency x Response Repetition x Picture Condition). The analysis was based on a medium-large effect size (partial eta squared = 0.1; Cohen, 1988), 80% power, and a low correlation (r = 0.24) between repeated measures. The results indicated that a sample size of 46 participants would be required to observe this interaction effect.

1.4.1.2 Groups

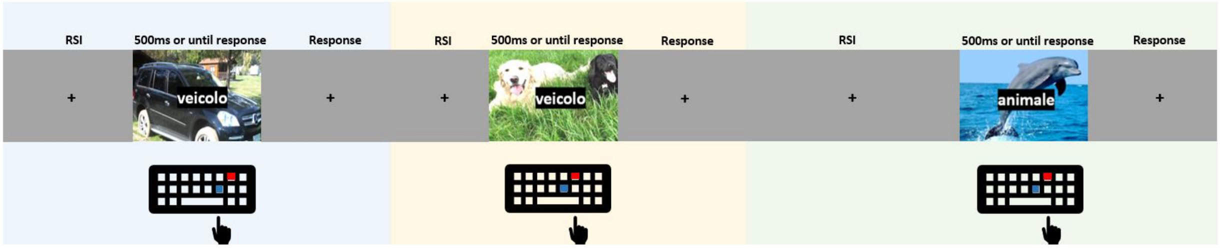
The participants were divided into two groups, which differed only in terms of the pictures used in the task. The pictures were assigned to each different task across participants (superordinate categorization: animal vs. vehicle; environment categorization: indoor vs. outdoor; enumeration: one vs. two foreground objects). One group (hereafter, “Novel Picture” condition) categorized all different pictures – 576 different images. The other group (hereafter, “Frequent Picture” condition) categorized six pictures that were selected from the original 576 dataset.

1.4.1.3 Stimuli

The experimental stimuli were composed of 576 different images. The picture database was created along three orthogonal dimensions: content (animal or vehicle), number of foreground objects (one or two), and scenario (indoors or outdoors). Hence, each picture showed one or two foreground objects (animal or vehicle) in an indoor or outdoor scenario, for a total of eight possible combinations equally distributed. The images were colored and balanced for brightness and contrast, pixel intensity M=153 and SD= 5.05 on a 0-255 scale. Each full-screen picture was resized to a 1280x1024 pixel monitor subtending 20°30' horizontal x 16°20' vertical degrees of visual angle. A word was presented along with the picture. The word was printed in Italian – "veicolo" ("vehicle"), "animale" ("animal"), "uno" ("one"), "due" ("two"), "interno" ("indoor"), and "esterno" ("outdoor") – and it could be congruent (50%) or incongruent (50%) with the categorization to be done. For example,a picture that showed an indoor scenario with the word "indoor" was a congruent trial, while the same picture with the word "outdoor" was an incongruent trial. The white words in Courier New 70 font were displayed at the center of the monitor, surrounded by a black rectangle (15°8' horizontal x 2°33' vertical degrees of visual angle), as shown in Figure 6.

Figure 6

Trial procedure in Novel Picture condition



1.4.1.4 Procedure

After filling out the informed consent form, the participant was accompanied to the experimental room that was set at 3 lux, measured using a diode-type digital luxmeter. The task was divided into three blocks of 192 trials that involved a different task: categorization of the objects in the forefront (animal or vehicle), number categorization of the objects in the forefront (one or two), and the categorization of the scenario (outdoors or indoors). The order of the blocks was counterbalanced across participants. The participant categorized the picture by ignoring the word and giving equal importance to speed and accuracy. The keys to be pressed for the response were J and N on the QWERTY computer keyboard. The participants had to respond with two fingers of the dominant hand. The response key was counterbalanced across participants. The distance between the participant and the monitor was 94 cm. Eight practice trials prior to each experimental block were presented, with different images from those used in the experimental blocks. After each block, there was a short break. Each trial started with a picture, which was presented for 500 ms or until the participant's response was given. If the participant did not respond during the image, a central fixation cross appeared until the response. After the response, a response-stimulus interval (RSI) ranging from 750 to 5000 ms was presented. Then, the next trial started; an example is reported in Figure 5. The experiment lasted approximately 30 min. The different RSI levels (750, 1000, 1500, 2000, 3000, 5000 ms) were evenly distributed and randomized across trials. Stimuli were presented in pseudo-random sequences that had the following specific constraints: not more than five consecutive trials with the same or alternate responses, not more than five consecutive trials with the same or alternate congruence conditions, and not more than five consecutive trials with the same or alternate RSI levels. Out of the 576 stimuli, half were congruent (C) and half incongruent (I). Considering the previous congruence, each of the four possible sequences (i.e., previous trial congruent or incongruent, followed by either a congruent or an incongruent trial) was presented with equal probability (48 trials for each congruence condition, in each task block). Moreover, each of the four combinations was equally paired with each of the RSIs, for a total of eight trials for each condition, in each task block. The experiment was run using E-Prime 2.0 Professional.

1.4.1.5 Analysis

Practice trials, trials which followed an error or in which an inaccurate response was given (accuracy in Frequent Picture condition: M =.977, SD = .020; accuracy in Novel Picture condition: M =.963, SD = .035), the first trial of each block, and trials with RTs exceeding 2.5 standard deviations (SD) from the mean RTs were excluded from the RT analyses. The Block factor 3 levels (Content, Numeric, Scenario) was collapsed since the interaction with the Current and Previous Congruence was not significant. Mean RT data were analyzed with a repeated-measures ANOVA, with the factor Picture Frequency as the between-subjects factor (2 levels: Novel, Frequent) and with the following within-subject factors: RSI (3 levels: Fast [750-1000ms], Medium [1500-2000ms], Slow [3000-5000ms]), Response Repetition (2 levels: Repeated response, Changed response), Previous Congruence (2 levels: Congruent [PreC], Incongruent [PreI]). The partial eta squared statistic (η_p^2) was calculated and reported. Huynh-Feldt correction was used when appropriate.

1.4.2 Results

Response times are reported in Figure 7.

A main effect of Current Congruence was significant, $F(1,78)=61.668$, $p<.001$, $\eta_p^2=.442$, with slower responses for incongruent compared with congruent trials (M=685.230 ms, SD=117.985; M=661.963 ms, SD=163.477, respectively).

The two-way interaction between Current and Previous Congruence was significant, $F(1,78)=10.376$, $p=.002$, $\eta_p^2=.117$. Slower responses were observed for incongruent compared with congruent trials, when they were preceded by congruent trials and when they were preceded by incongruent trials (PreC condition: $F(1,78)=52.131$, $p<.001$, $\eta_p^2=.401$; PreI condition: $F(1,78)=23.546$, $p<.001$, $\eta_p^2=.232$). Moreover, responses to incongruent trials were slower when they were preceded by congruent trials compared with incongruent trials, $F(1,78)=3.970$, $p=.050$, $\eta_p^2=.048$, while responses to congruent trials were slower when they were preceded by incongruent, compared with congruent trials, $F(1,78)=7.795$, $p=.007$, $\eta_p^2=.091$.

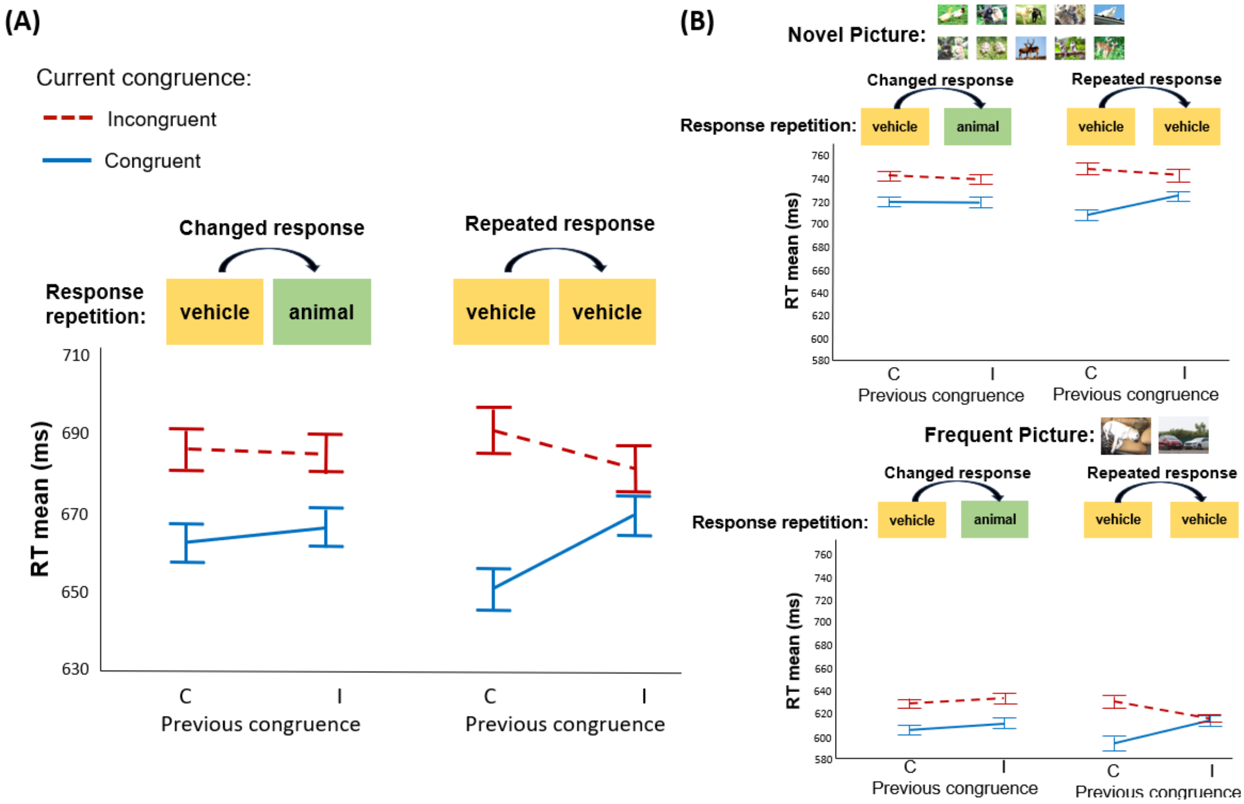
The three-way interaction between Response Repetition, Previous Congruence, and Current Congruence was significant, $F(1,78)=10.909$, $p=.001$, $\eta_p^2=.123$, as shown in Figure 7, panel A. Following this result, the interaction between Previous and Current Congruence was assessed in the repeated response condition and in the changed response condition, and it was significant only for repeated responses, $F(1,78)=15.190$, $p<.001$, $\eta_p^2=.163$, with a reduction in the interference effect in trials following incongruent trials compared to congruent trials. The responses were slower during the incongruent trials compared to the congruent trials when they were preceded by congruent trials, $F(1,78)=43.650$, $p<.001$, $\eta_p^2=.359$, and when preceded by incongruent ones, $F(1,78)=5.914$, $p=.017$, $\eta_p^2=.070$. Slower responses to congruent trials were observed when they were preceded by incongruent, compared with congruent trials, $F(1,78)=11.778$, $p=.001$, $\eta_p^2=.131$, and for incongruent trials when they were preceded by congruent, compared with incongruent trials, $F(1,78)=5.751$, $p=.019$, $\eta_p^2=.069$. The interaction between Previous and Current Congruence was not significant in the changed response condition, $F(1,78)=.851$, $p=.359$, $\eta_p^2=.011$, as shown in Figure 7, panel B.

The interactions between Picture Frequency, Previous, and Current Congruence and between Response Repetition, Picture Frequency, Previous, and Current Congruence were not significant, $Fs\leq.418$, $ps\geq.520$, $\eta_p^2s \leq.005$.

Regarding the Response-Stimulus Interval (RSI), the most important interactions were not significant: Interaction between RSI, Previous, and Current Congruence; interaction between RSI, Response Repetition, Previous and Current Congruence; interaction between RSI, Picture Frequency, Previous, and Current Congruence ($Fs\leq.616$, $ps\geq.541$, $\eta_p^2s \leq.008$).

Figure 7

(A) Mean RT data as a function of Previous and Current Congruence in Repeated and Changed responses. (B) Mean RT data as a function of Previous and Current Congruence in Repeated and Changed responses, separated by Novel and Frequent picture conditions



Note. Red (dashed) lines reflect the current incongruent trials, and blue (solid) lines represent the current congruent trials. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005).

1.4.3 Discussion

The behavioral experiment aimed to study whether the modulation of the binding-retrieval process within episodic representations on cognitive control was exclusively driven by the features that are shared among several stimuli (here superordinate category), as suggested by previous research (Kreutzfeldt et al., 2016; Yang et al., 2017- Exp1A, 3A; Grant et al., 2020; Grant and Weissman, 2023, Kelber et al., 2023; Schiltenwolf et al., 2024; Dignath et al., 2021; Spapè and Hommel, 2008; Dignath and Kiesel, 2021; Dignath et al., 2019), or whether feature belonging to individual stimuli (here, perceptual/sensory features) also plays a role. The results suggest that CSE – considered a behavioral index of cognitive control – is modulated by the repetition of superordinate categories of stimulus rather than perceptual/sensory feature ones.

1.5 Experiment 2 – Electrocortical CSE during the trial repetition

Since the aperiodic exponent can be considered a cortical index of cognitive control, the EEG experiment aimed to investigate not only the behavioral response but also the electrophysiological response. The modulation of the aperiodic component by previous interference may arise from the conflict experienced in the previous conflict (Jia et al., 2024). However, in the present study, we ask whether, in addition to conflict, the binding-retrieval process within episodic representation also plays a role in modulating the electrophysiological response related to cognitive control, as observed in the behavioral response. If such modulation is observed, the key question is which repeated stimulus feature – superordinate category or perceptual/sensory feature – plays the most crucial role. To this end, we replicated the previous study by including the aperiodic components as a dependent variable, in addition to response times. Compared to the previous study, the repetition of images was treated as a within-subjects factor.

1.5.1 Method

1.5.1.1 Participants

Fifty participants (19 females, age M=26.3, SD= 3.352), all fluent in Italian and with normal or corrected vision, took part in the experiment. Data from 49 participants were analyzed due to one participant failing to comply with task instructions. The experimental protocol adhered to the principles outlined in the Declaration of Helsinki and received approval from the Ethical Committee of the University of Bologna. A power analysis was conducted using R (package pwrss; Bulus, 2023) to determine the required sample size based on the four-way interaction of interest (Current Congruency x Previous Congruency x Response Repetition x Picture Condition). The analysis was performed assuming a medium-large effect size (partial eta squared = 0.1; Cohen, 1988), 80% power, and a low correlation (r = 0.24) between repeated measures. The results indicated that a sample size of 20 participants would be required to detect this interaction effect.

1.5.1.2 Stimuli

The experimental stimuli involved a set of 488 different pictures taken from those used in the behavioral experiment. Of these 488 pictures, 480 were used in a block – where each trial involved a new picture (i.e., Novel Picture condition; see 1.5.1.3). The remaining eight images were used to create the four pairs of images, which the participants viewed only in another block - where the same pictures were repeated across trials (i.e., Frequent Picture condition; see 1.5.1.3). Hence, participants viewed 480 unique images in one block, and two images from the four pairs, which were repeated 240 times in the other block.

1.5.1.3 Procedure

The procedure was the same as the behavioral experiment, but with the following differences. Participants categorized the pictures only as animals or vehicles in the Picture Word Interference (PWI) task. The task was divided into two blocks of 480 trials each: Novel Picture condition (480 different pictures that were never repeated) and Frequent Picture condition (two pictures repeated 240 times each). The experiment lasted approximately 60 min, with eight practice trials preceding each experimental block to familiarize participants with the task. Each trial started with the presentation of an image for 500 ms, followed by a response-stimulus interval (RSI) of varying durations (1000, 2000, 3000, or 5000 ms) before the next trial began. Out of the 480 stimuli, half were congruent (C) and half incongruent (I). Considering the congruence level of the previous trial, each of the four possible sequences (PreC-C, PreC-I, PreI-C, PreI-I) was presented with equal probability (120 trials for each congruence condition, in each block). Moreover, each of these four combinations was equally paired with each of the RSIs resulting in 30 trials for each condition, in each block.

1.5.1.4 EEG data acquisition and preprocessing

Scalp EEG was recorded from 64 Ag/AgCl active electrodes using the BioSemi ActiveTwo system. The electrodes were secured in an elastic cap according to the extended 10-20 international electrode placement system (Jasper, 1958). Horizontal and vertical electrooculograms (EOGs) were also recorded to monitor ocular artifacts. During recording, data were written to the file referenced to the common mode sense (CMS) electrode and were filtered online with a low pass filter equal to 1/5 of the sampling rate (i.e., 102.4 Hz). The sampling rate was 512 Hz. The data were preprocessed using custom MATLAB 2022b codes (The MathWorks) incorporating EEGLAB 13.6.5 (Delorme and Makeig, 2004) and ERPlab 6.1.3 (Lopez- Calderon and Luck, 2014). The EEG was first re-referenced to the average mastoids and bandpass filtered with 0.1 and 40 Hz cut-off frequencies. The pre-event time for epoching was -1000 ms and the post-event was 3000 ms. After excluding epochs with amplifier saturation and performing ocular correction (Gratton et al., 1983), epochs with peak-to-peak voltage fluctuations at any EEG channel exceeding 200 μV (1000-ms window width, 10-ms window step) were discarded. Epochs with incorrect trials and trials preceded by incorrect ones, the first trial of each block and those beyond 2.5 SD from the mean of reaction times were excluded. Data from frontal and peripheral electrodes (i.e., A1, A2, Fp1, Fp2, AF3, AF4, AF7, AF8, AFz, FPz, P9, P10, Iz) were excluded as they contain small residual ocular artifacts even after ocular correction. The average number of artifact-free epochs was 694.022 out of 960 (SD=152.869, min=366, max=893).

1.5.1.5 Behavioral analysis

Practice trials, trials that followed an error or in which an inaccurate response was given, the first trial of each block, and trials with RTs exceeding 2.5 standard deviations (SD) from the mean RTs were excluded from the RT analyses. The RSI factor 4 levels (1000, 2000, 3000, 5000 ms) was collapsed since the interaction with the Current and Previous Congruence was not significant in the previous behavioral experiment. Mean RT data were analyzed with repeated-measures ANOVA, with the following within-subject factors: Picture Frequency (2 levels: Novel, Frequent), Response Repetition (2 levels: Repeated, Changed), Previous Congruence (2 levels: Congruent [PreC], Incongruent [PreI]), and Current Congruence (2 levels: Congruent [C], Incongruent [I]). Huynh-Feldt correction was used when appropriate. The partial eta squared statistic (η_p^2) was calculated and reported.

1.5.1.6 Spectral analysis

Potential Related Events (ERPs) were calculated and eliminated from the spectral analyses. For each frequency, a convolution process was convolved using complex Morlet wavelets. To optimize temporal resolution, only one-cycle wavelet was used for analysis. Additionally, to expedite computations and mitigate potential overlaps between adjacent frequencies, and to exclude the alpha range that could distort the slope estimation, we restricted the wavelet analysis to five frequencies: 2.5, 5, 7.5, 15, and 25 Hz. Epoched data (-300 ms to 1300 ms, step=160 ms) were then averaged across trials for each experimental condition and participant, with baselines (from 300 ms before stimulus onset to stimulus onset) subtracted from each time point and condition. Subsequently, the regression slopes were computed for each data point. The RSI factor was collapsed as in the behavioral analyses. Aperiodic exponent was analyzed with a repeated-measures ANOVA, with the following within-subject factors: Picture Frequency (2 levels: Novel, Frequent), Response Repetition (2 levels: Repeated, Changed), Previous Congruence (2 levels: Congruent [PreC], Incongruent [PreI]), and Current Congruence (2 levels: Congruent [C], Incongruent [I]). Huynh-Feldt correction was used when appropriate. From the electrodes used in the study by Jia et al. (2024), we selected the following electrode clusters after a visual inspection of the activity across the entire scalp: right cluster (C2, C4, C6, CP2), left cluster (C1, C3, C5, CP1), central cluster (Fz, FCz, Cz, CPz), and occipital cluster (POz, Oz, O2, O1). Regarding the time window, we chose the same parameters (0-1000 ms after stimulus onset) as Jia et al. (2024) and Zhang et al. (2023). To achieve better temporal resolution, we reduced it to 500–980 ms. Since the results were replicated, we decided to maintain the reduced time window.

1.5.2 Results

1.5.2.1 Behavioral results

Response times are reported in Figure 8.

A main effect of Current Congruence was significant, $F(1,48)=16.885$, $p< .001$, $\eta_p^2=.260$, with slower responses for incongruent compared (M=656.391 ms, SD= 147.353) to the congruent trials (M=641.835 ms, SD=132.265).

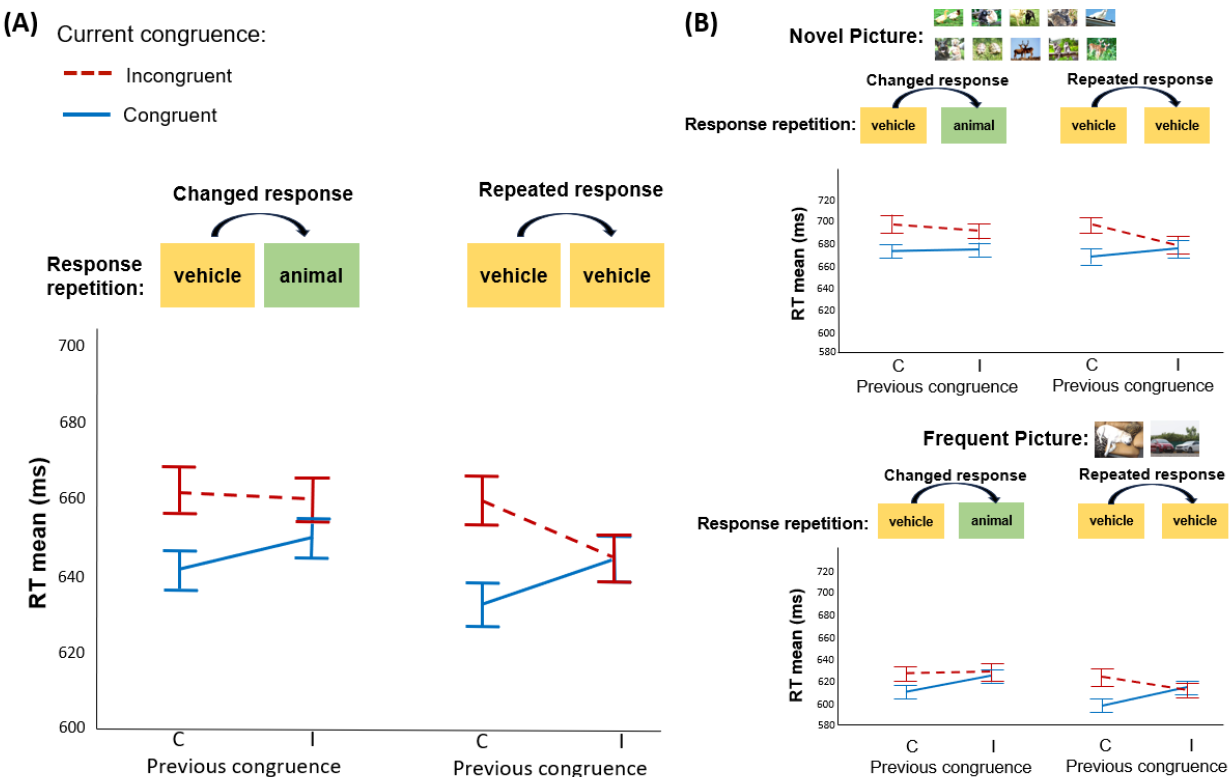
The two-way interaction between Current and Previous Congruence was significant: $F(1,48)= 20.309$, $p<.001$, $\eta_p^2=.297$. Following this interaction, slower responses were observed for incongruent compared to congruent trials when they were preceded by congruent trials, PreC condition: $F(1,48)= 28.446$, $p<.001$, $\eta_p^2=.372$. Moreover, responses to incongruent trials were slower when they were preceded by a congruent compared with an incongruent trial, $F(1,48)= 15.701$, $p<.001$, $\eta_p^2=.246$, while responses to congruent trials were slower when they were preceded by incongruent compared with congruent trials, $F(1,48)= 9.589$, $p=.003$, $\eta_p^2=.167$.

The three-way interaction between Response Repetition, Previous Congruence, and Current Congruence was significant, $F(1,48)= 6.215$, $p=.016$, $\eta_p^2=.115$. Following this result, the interaction between Previous and Current Congruence was significant only for repeated responses, $F(1,48)= 19.414$, $p<.001$, $\eta_p{}^2=.288$, with slower RTs in incongruent compared to congruent trials when they are preceded by congruent trials, PreC condition: $F(1,48)= 19.245$, $p<.001$, $\eta_p{}^2=.286$. Slower responses to congruent trials were observed when they were preceded by congruent compared to when they were preceded by incongruent trials, $F(1,48)= 6.183$, $p=.016$, $\eta_p{}^2=.114$. Then, incongruent trials were associated with faster responses when preceded by incongruent trials, compared to when they were preceded by congruent ones, $F(1,48)= 16.901$, $p<.001$, $\eta_p{}^2=.260$. The interaction between Previous and Current Congruence was not significant in the changed response, $F(1,48)=.585$, $p=.448$, $\eta_p{}^2=.012$.

Finally, the interactions between Picture Frequency, Previous Congruence, and Current Congruence and between Picture Frequency, Response Repetition, Previous Congruence, and Current Congruence were not significant, Fs≤.585, ps≥.448, η2ps ≤.012.

Figure 8

(A) Mean RT data as a function of Previous and Current Congruence in Repeated and Changed responses. (B) Mean RT data as a function of Previous and Current Congruence in Repeated and Changed responses, separated by Novel and Frequent picture conditions



Note. Red (dashed) lines reflect the current incongruent trials, and blue (solid) lines represent the current congruent trials. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005).

1.5.2.2 Aperiodic exponent results

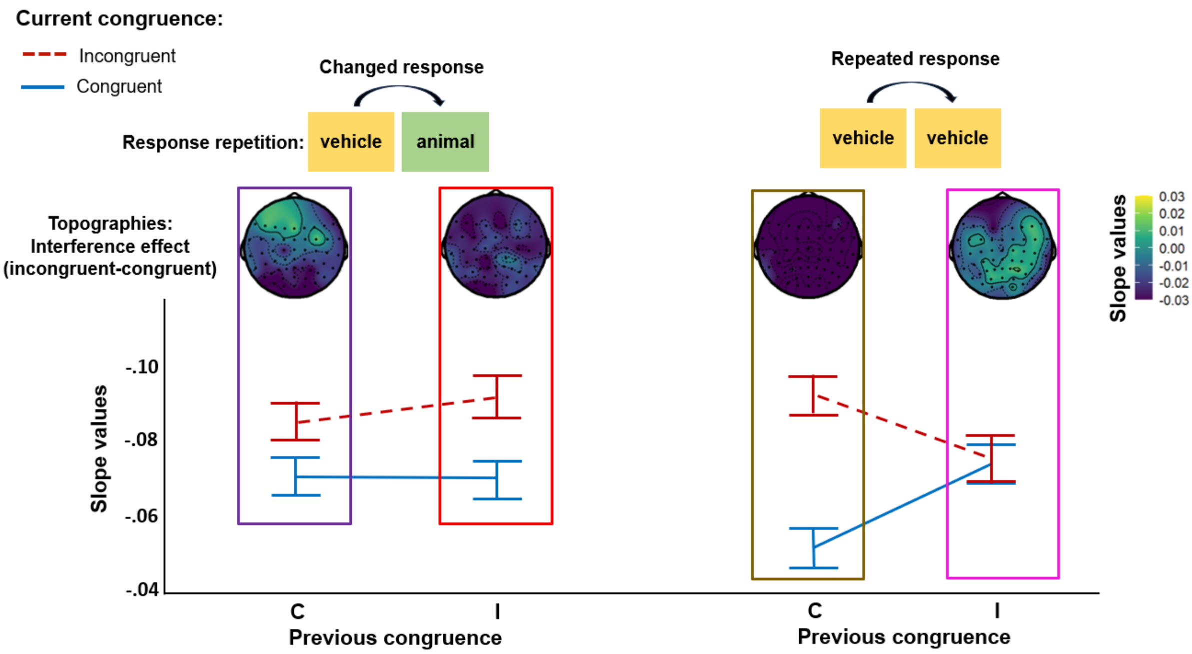
A main effect of Current Congruence was significant, $F(1,48)=27.333$, $p<.001$, $\eta_p^2=.363$, with more negative exponent for incongruent ($M= -.087$, $SD=.054$) compared to the congruent trials ($M= -.066$, $SD=.051$).

The two-way interaction between Current and Previous Congruence was not significant, $F(1,48)= 3.585$, $p=.064$, $\eta_p^2=.069$.

The three-way interaction between Response Repetition, Previous Congruence, and Current Congruence was significant, $F(1,48)= 7.773$, $p=.008$, $\eta_p^2=.139$, as shown in Figure 9. Following this result, the interaction between Previous and Current Congruence was significant only for repeated responses, $F(1,48)= 7.767$, $p=.008$, $\eta_p^2=.139$. We observed higher aperiodic exponent during incongruent trials compared to congruent trials when they are preceded by congruent trials, $F(1,48)= 25.384$, $p<.001$, $\eta_p^2=.346$, and higher aperiodic exponent during congruent trials when they were preceded by incongruent compared to when they are preceded by congruent trials, $F(1,48)=7.391$, $p=.009$, $\eta_p^2=.133$. The interaction between Previous and Current Congruence was not significant in the changed response, $F(1,48)= .595$, $p= .444$, $\eta_p^2=.012$, but the main effect of the congruency was significant – $F(1,48)=9.631$, $p=.003$, $\eta_p^2=.167$.

Figure 9

Slope values of exponent component



Note. In the upper part of the image, there are the topographies of the interference effect of the aperiodic exponent, separated by the previous congruence and response repetition condition, in the time window from 500 to 980 ms after the onset of the stimulus. At the bottom, there is the RT mean data as a function of Previous and Current Congruence in Repeated and Changed responses. Red (dashed) lines reflect the current incongruent trials and blue (solid) lines represent. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005).

Finally, the interactions between Picture Frequency, Previous Congruence, and Current Congruence and between Picture Frequency, Response Repetition, Previous Congruence, and Current Congruence were not significant, $Fs \leq .776$, $ps \geq .383$, $\eta_p{}^2 s \leq .016$.

1.6 Discussion

The first chapter of the present thesis studied which repetitions of features in episodic representation (i.e., superordinate category or perceptual/sensory feature) can modulate cognitive control, both at the behavioral and electrocortical levels. We used a picture-word interference task in two experiments (behavioral and EEG), with the focus on identifying which repeated features of the previous trial can lead to larger CSE.

In the behavioral experiment, a modulation of CSE depending on the repetition of the response category was observed. Specifically, we observed a significant CSE in trials during response repetition, but not during changes in the response. This pattern is consistent with previous studies (Kreutzfeldt et al., 2016; Yang et al., 2017-Exp1A, 3A; Grant et al., 2020; Grant and Weissman, 2023, Kelber et al., 2023; Schiltenwolf et al., 2024; Dignath et al., 2021; Spapè and Hommel, 2008; Dignath and Kiesel, 2021; Dignath et al., 2019), which observed smaller or absent CSE during changes in features of the previous trial compared to the repetition. According to the BRAC model (Frings et al., 2020), stimulus features, responses, and attention involved during a trial are integrated and stored in episodic representations. If a feature from a previous stimulus is repeated, other elements of the episodic representation are reactivated, including the control mechanism that resolved the previous conflict if an incongruent trial had occurred, resulting in better performance in the next trials (Egner, 2014; Abrahamse et al., 2016; Dignath et al., 2019; Frings et al., 2020 Verguts and Notebaert, 2009). The model does not define which types of features are included in the episodic representation. Both the present results and those in the literature suggest a modulation by the features that are shared among several stimuli. De Cesarei et al. (2023) found that the repetition of pictures leads to a larger CSE. However, it was not possible to separate the effect of sensory/perceptual features belonging to each stimulus from the repetition of the stimulus category. To address this, we implemented two different conditions using novel and frequent images. Our findings showed that the effect of the identity repetition did not add to the repetition of the category, suggesting that here only the superordinate category feature is involved in episodic representation. The same pattern of results was observed in the within-participants design experiment (i.e, the EEG experiment).

Regarding the aperiodic component, we observed higher aperiodic exponent during incongruent than congruent trials, suggesting an inhibition of synaptic circuits during the conflict conditions (Zhang et al., 2023; Jia et al., 2024). Furthermore, the interference effect observed in the aperiodic exponent was modulated by the previous conflict only during an event repetition condition. This result suggests that the CSE observed in the aperiodic exponent, within the 500-980 ms time window, could reflect not only activation due to the conflict of the condition (Zhang et al., 2023; Jia et al., 2024) but also the binding-retrieval process involved in episodic representation (Fring et al., 2020). Thus, even at the electrophysiological level, repetition of a previous event feature might facilitate cognitive control activation in the next event. Moreover, this modulation was observed only during response repetition (i.e., the repetition of features shared among different stimuli), as observed in the behavioral results of this study (Kreutzfeldt et al., 2016; Yang et al., 2017-Exp1A, 3A; Grant et al., 2020; Grant and Weissman, 2023, Kelber et al., 2023; Schiltenwolf et al., 2024; Dignath et al., 2021; Spapè and Hommel, 2008; Dignath and Kiesel, 2021; Dignath et al., 2019) and in Experiment 1. This finding suggests that the repetition of features belonging to an individual stimulus did not affect the modulation of cognitive control from the repetition of features shared among different stimuli. Future research may also study other electrocortical correlates of cognitive control, such as theta oscillations (4-7 Hz) since it could reflect cortical mechanisms involved during conflict conditions (Cohen, 2014; Cavanagh et al. 2012; Cohen and Cavanagh et al. 2011; Hanslmayer et al. 2008; Nigbur et al., 2011; 2012; Gratton, 2018).

It would also be worthwhile to investigate the repetition of other features defined as perceptual/sensory features (e.g., blurriness, size of pictures, etc.). Additionally, in our paradigm, response repetition involved repeating the category as well. This aspect was not studied in the present thesis to avoid adding complexity to the experimental design, as the primary research question centered on whether repeating perceptual/sensory features (i.e., identity images) could influence the CSE alongside superordinate category feature repetition. Future studies could implement a design that minimizes confounding factors to clarify whether the modulation of superordinate category repetition is linked to changes in the categorized stimulus feature or solely to response repetition.

Chapter 2: Cognitive control and emotional interference

2.1 Interference effect caused by the attentional capture of emotional stimuli

Attentional capture can refer to the shift of attention toward a prominent but irrelevant stimulus (Theeuwes, 1992). Research indicates that the allocation of attention to stimuli results from the interplay between two mechanisms: The top-down (i.e., goal-directed, depending on internal knowledge, goals, and instructions given during a task) and the bottom-up mechanism (i.e., stimulus-driven, depending on the intrinsic properties of sensory stimuli present in the environment) (Connor et al., 2004; Corbetta and Shulman, 2002; Itti and Koch, 2001). This dichotomy was questioned by Awh et al. (2012), who proposed an integrative framework for understanding different types of selection bias. They emphasized the concept of a "priority map" that combines three distinct sources of bias. The first regards “current goals”: Shifts in an individual’s goals can actively modify selection biases, allowing attention to align with intentional objectives. The second source of bias reflects “selection history”, which originates from past experiences, including the history of selection and rewards. The authors describe how previous experiences, often subconsciously, influence attention. For example, targets with a high likelihood of appearing are more easily stored in working memory, even when observers are unaware of these probabilities. This type of bias aligns with associative learning models, highlighting how previous selection events shape responses in future situations, sometimes even superseding goal-directed selection. The last source of bias is “physical salience”: This category addresses selection based purely on the intrinsic properties of stimuli, independent of the observer’s mental state. The authors argue that stimuli with high emotional significance also capture attention, due to evolutionary adaptation. Physical salience, therefore, remains an important category for attentional control, capturing the strong influence of low-level stimulus attributes.

Emotional stimuli are known for their characteristics to capture attention due to their survival relevance, enabling them to access processing resources effortlessly (Dolan, 2002). An emotional response refers to the reaction to a stimulus that involves two primary factors: arousal and valence (pleasantness or unpleasantness) (Barrett and Russell, 1999). These two dimensions – valence and arousal – are central to understanding emotional experiences, as they explain most of the variation in individuals' subjective reports regarding emotional stimuli (Bradley et al., 2001). Furthermore, research has demonstrated that when emotional images are presented alongside a target stimulus but are unrelated to the task, they cause slower reaction times compared to neutral distractors (Bradley et al., 1999), leading to an interference effect. This effect has been observed in both visual and auditory tasks, suggesting that emotional stimuli can impair task-related processing (Bradley et al., 1996, 1999; Calvo and Nummenmaa, 2007; Okon-Singer et al., 2007).

In a meta-analysis, Zhang et al. (2023) studied whether and how emotional stimuli influence cognitive control, focusing on studies that combined conflict tasks with emotional stimuli irrelevant to the task. Their findings showed that emotional stimuli can modulate cognitive control in conflict situations by reducing the interference effect compared to neutral stimuli, but only under specific conditions. Namely, emotional stimuli could reduce interference when presented alongside the target rather than before or after it. Studies found that certain stimulus formats, such as words and videos, were more effective in reducing interference compared to others, like emotional pictures. A moderator analysis revealed that negatively threatening stimuli heightened the interference effect more than positive stimuli. The authors conclude that highly significant stimuli – particularly those that are threatening and highly arousing – demand resources essential for cognitive control, increasing interference.

Additionally, if the arousal from distractor stimuli does not directly compete with task-relevant stimuli, the processing of neutral, task-relevant information should be enhanced, reducing the processing of distractors (Mather and Sutherland, 2011).

In support of this, Zeng et al. (2017) observed a stronger congruency sequence effect (CSE) with both positive and negative arousing words compared to neutral words. The emotional words were used as emotional context in a color-word flanker task in which participants were instructed to name the print color of the central word. These results suggest that emotional arousal – regardless of valence – enhances cognitive control.

On the other hand, some studies did not observe any modulation of arousal on the interference effect. For example, De Cesarei et al. (2023) found no evidence that novelty-induced arousal influenced the CSE. Similarly, Dignath et al. (2017) observed no modulation of interference reduction by arousal. They hypothesized that if high-arousal images enhanced CSE, which would be more pronounced after highly arousing images than after low-arousal ones, regardless of emotional valence. Their findings indicated that CSE remained consistent across both levels of arousal. Similarly, Brown et al. (2014) also found that task-irrelevant phasic arousal manipulation did not affect interference.

2.2 Can the emotional response be modulated by the perceptual/sensory characteristics of the emotional stimulus?

In the literature, it has been studied whether specific characteristics of emotional stimuli can influence emotional response. For example, Codispoti and De Cesarei (2007) studied whether the variation of picture size could affect emotional modulation. The authors observed that subjective ratings of arousal and valence were only minimally affected by the size of the pictures: Smaller images elicited weaker affective modulation in both ratings compared to larger images. This may be because smaller stimuli are perceived as more distant and less immediate, resulting in a less intense emotional response, while larger stimuli are seen as more imminent and urgent (De Cesarei and Codispoti, 2008).

However, image size is not the only manipulation that can influence emotional responses – such as skin conductance and subjective ratings of valence and arousal. When an object is reduced in size, its finer details become imperceptible, falling below the threshold of detection. Another way to operationalize, measure, and manipulate the appearance of a scene is through spatial frequencies, which refer to the number of times each detail can fit into a unit of space. Small details fit a high number of times (hence, high spatial frequencies), while larger areas fit a lower number of times (low spatial frequencies). As a result, the presence of perceptual/sensory details associated with higher spatial frequencies (i.e., finer details in visual stimuli, such as textures, edges, and small features) could influence emotional processing, even when the visual angle remains unchanged. For this reason, De Cesarei and Codispoti (2008) studied the impact of size reduction and image degradation through low-pass filtering (i.e., manipulation of scene appearance that allows large areas to be displayed while canceling out all finer details, resulting in a blurred version of the original scene) on subjective emotional ratings. In addition to subjective ratings, they also studied how image degradation affected emotional attentional capture, using degraded images as distractors in an auditory discrimination task. The authors observed two outcomes regarding attentional capture and subjective responses of valence and arousal: Despite the size reduction and degraded images diminished the subjective responses, even the more degraded images showed the same attentional capture as the intact images, interfering with the ongoing task. No differences were found between the effects of size reduction and low-pass filtering in subjective ratings (De Cesarei and Codispoti, 2008).

Several studies have demonstrated that manipulating specific details did not directly affect emotional responses. Emotional modulation only occurred when the image quality was sufficient for participants to identify the emotional content. If participants were unable to identify the content of the emotional image, no affective modulation was observed (Beligiannis et al., 2022; Codispoti et al., 2021; Storbeck et al., 2006; Mastria et al., 2024).

2.3 Research questions and hypotheses

When arousal from stimuli does not directly compete with task-relevant stimuli, it should enhance the processing of neutral, task-relevant information while reducing distractor processing (Mather and Sutherland, 2011). This has been evidenced by a stronger congruency sequence effect (CSE), observed when emotional words are used as context in a two-colour-word Flanker task compared to neutral words, indicating that emotional arousal improves cognitive control performance (Zeng et al., 201). The activation of cognitive control triggered by the conflict task was strengthened by emotional arousal in the study by Zeng et al. (2017). In the absence of a conflict task, is cognitive control activated to inhibit the attentional capture of distractors? To answer this question, we replicated the paradigm used by Codispoti et al. (2016): Participants rapidly categorized two digits as having the same parity (i.e., both odd or both even) or different parity (i.e., one even number and the other odd). During the task, emotional or neutral pictures appeared between the two digits on each trial, and the participants had to ignore them. According to the literature (Bradley et al., 1996, 1999; Calvo & Nummenmaa, 2007; Okon-Singer et al., 2007), we expect to observe attentional capture by emotional stimuli in the current trials, with response times for categorizing the number pair being slower during emotionally charged images compared to neutral ones. If arousal stimulus enhances cognitive control, can this enhancement lead to a reduction in interference from arousal stimuli in the subsequent trial? Hence, if interference is reduced after emotional distractors compared to neutral ones (Zeng et al., 2017), we may conclude that emotional stimuli trigger cognitive control, consistent with observations made during exposure to incongruent stimuli (i.e., CSE; Gratton et al., 1992). However, we might not observe any modulation of cognitive control by arousal images, as has been observed by Dignath et al. (2017), De Cesarei et al. (2023), and Brown et al. (2014).

Furthermore, previous studies have shown that even the degraded images elicit an effective response (De Cesarei and Codispoti, 2008; Beligiannis et al., 2022). Nonetheless, the repeated degradation levels of previous arousal stimuli could modulate the attentional capture of emotional stimuli, as recent models suggest that repeating stimulus characteristics may influence cognitive control, leading to a greater reduction in interference effects during stimulus repetition. (Frings et al., 2020). In the previous chapter, we manipulated both superordinate categories and perceptual/sensory features of stimuli, observing modulation only by the repetition of superordinate categories. The present chapter focuses on the repetition of other perceptual/sensory features of stimuli. The manipulation of the stimulus perceptual/sensory features focused on the target in the previous chapter, whereas in this chapter, the sensory-level characteristic of the distractors – blurriness – is manipulated. To this end, the emotional images were presented either intact or degraded. Hence, the second aim is to study whether the reduction in interference caused by the preceding emotional distractor is influenced by the repetition of a perceptual/sensory feature of an image (i.e., blurriness). If all image features, including perceptual/sensory ones, are relevant for cognitive control activation, we might expect a greater reduction in interference after the emotional distractor when the level of the image degradation is repeated compared to when it is not repeated (Frings et al., 2020). However, we may observe no modulation of the repetition of the degradation level, similar to the previous chapter, where there was no modulation of the repetition of the perceptual features of the stimuli.

Before conducting this study, we ran an experiment to determine whether the emotional response is preferentially tied to any spatial frequency (i.e., the level of detail present in an image, where low spatial frequencies correspond to broad patterns, such as the overall shape or large features, while high spatial frequencies correspond to fine details). If this was the case, then it would be appropriate to adopt a manipulation that preserves this information. Additionally, we studied which spatial frequency filter to use (i.e., whether low-pass or high-pass), as it was crucial for our purposes that scene identification remained intact even after applying the filter since the ability to discriminate the emotional content of the image is necessary to observe the affective modulation (Beligiannis et al., 2022; Codispoti et al., 2021; Storbeck et al., 2006; De Cesarei and Codispoti, 2011, 2013).

2.4 Experiment 1 – Is the emotional response tied to a specific frequency range?

2.4.1 Method

2.4.1.1 Participants

Fifteen participants took part in the present study (12 females, mean age= 22.06, SD=1.39). All participants had normal or corrected-to-normal visual acuity, and none reported any current or past neurological or psychopathological issues. The experimental protocol conforms to the Declaration of Helsinki and was approved by the Ethics Committee of the University of Bologna. A power analysis was conducted based on a previous pilot sample of participants using G*Power 3.1 (Erdfelder et al., 1996) to determine the required sample size for the two-way interaction of interest (Spatial Frequency Band x Picture Content). The parameters used were α = 0.05, power = 0.80, partial eta squared (n_p^2) = 0.06 (a medium effect according to Cohen, J., 2013), and a correlation among repeated measures of 0.75. The analysis indicated a minimum required sample size of 8 participants.

2.4.1.2 Stimuli

Ninety images were selected from the International Affective Picture System (IAPS; Lang et al., 2008) and the Internet. The categories of the images included erotic couples (n=15, arousing and pleasant), babies (n=15, arousing and pleasant), individuals indoors or outdoors engaged in daily activities (n=30, neutral), attacks (n=15, arousing and unpleasant), and injuries (n=15, arousing and unpleasant). The images were consistent in terms of brightness and contrast (pixel intensity: M=128, SD= 72.11), clarity of both foreground and background, number of people (1 to 3 per image, with visible faces), and the proportion of the image occupied by each person's face (percentage of total image size: M=10.76%, SD= 3.41%). A band-pass filter was applied to each image, centred on the following spatial frequencies (F0): 4, 13.5, 45.3, 152.2, and 512 cpi. By combining the low-pass and high-pass filters, a band-pass filter is created. This filter allows only a specific range of frequencies to pass through, centered around F0. Frequencies lower than F0/3 (for the high-pass filter) and higher than F0x3 (for the low-pass filter) are blocked, meaning the filter focuses on the middle range of frequencies. Participants viewed images with each type of degradation. The images measured 21x17 cm, corresponding to a visual angle of 23.72° horizontally x 19.30° vertically. The experiment was conducted on a 17-inch monitor using OpenSesame software, version 3.2.7 (Mathôt et al., 2012).

2.4.1.3 Procedure

The experiment consisted of 90 trials, preceded by 4 practice trials. Each trial began with a fixation cross presented for 3000 ms, followed by an image displayed for 800 ms. After the image, a blank screen appeared for 300 ms. Next, the Self-Assessment Manikin (SAM; Lang, 1980; Bradley and Lang, 1994) was administered to rate the valence and arousal of the image on a 9-point scale. Finally, participants were asked to describe the scene with a short open response. The distance between the participant and the monitor was 50 cm. The experiment lasted approximately 60 minutes.

2.4.1.4 Data analysis

Practice trials were excluded from the analysis. As for the identification performance, a response was considered accurate if the participant's description matched the category of the picture. Arousal ratings were analyzed across different filtering bands, content of the pictures, and accuracy in the brief open responses. Identification performance was analyzed in repeated-measures ANOVAs, with Band (five levels: 4, 13.5, 45.3, 152.2, and 512 cpi) as within-subject factors. The Huynh-Feldt correction was applied when necessary, and partial eta squared (n_p^2) was calculated and reported. Since picture degradation was minimal for intermediate levels, accuracy was unevenly distributed, with missing data in the ANOVA design observed for trials with low accuracy in the intermediate spatial frequency bands and for trials with high accuracy in the lowest and highest spatial frequency bands. For this reason, we first used the multiple imputation method in Amelia II software. Participant was used as cross-sectional variable, while Degradation and Content were treated as nominal variables, and arousal and valence were treated as continuous variables with a range from 1 to 9. This approach generated five different datasets for analysis, and F values were pooled across these datasets. The p-values and partial eta-squared values were recalculated based on the pooled F values. Lastly, we conducted a control analysis without replacing the missing data, which confirmed the same overall pattern of results.

2.4.2 Results

2.4.2.1 Identification performance

A main effect of Band was observed, $F(4,56)=316.71$, $p<.001$, $\eta_p^2=.96$. Better identification in the intermediate bands (13.5, 45.3, and 152.2 cpi) was observed compared to the lowest (4 cpi) and highest (512 cpi) bands, and better identification in the lowest band compared to the highest band.

2.4.2.2 Arousal ratings

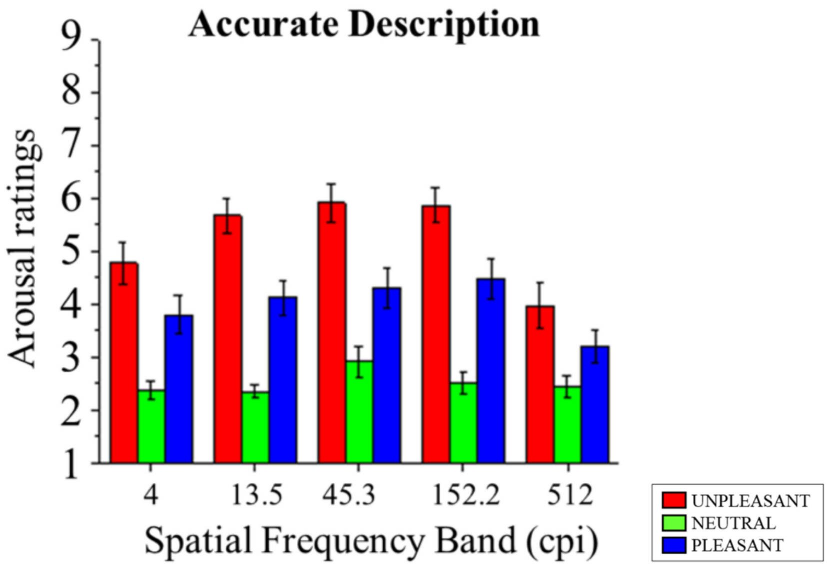
Considering only the accurate identification, a significant main effect of Content was found – $F(2,28)=39.10$, $p<.001$, $\eta_p^2=.74$ – showing that affective responses to both unpleasant and pleasant images were rated as more arousing than neutral images, $Fs(1,14)>27.90$, $ps<.001$, $\eta_p^2s>.67$.

The interaction between Band and Content was observed, $F(8,112)=2.50$, $p=.016$, $\eta_p^2s=.15$. Following this interaction, a main effect of Content was assessed in each band only for accurate trials. In all bands, there was a significant effect of Content – $Fs(2,28)>6.23$, $ps<.006$, $\eta_p^2s>.31$ – with higher arousal ratings for unpleasant and pleasant pictures compared with neutral ones – $Fs(1,14)>10.98$, $ps<.005$, $\eta_p^2s>.44$. However there were exceptions: In the highest band for pleasant vs. neutral – $F(1,14)=3.94$, $p = 0.067$, $\eta_p^2= 0.22$ – and in three intermediate levels in which unpleasant scenes were rated as more arousing than pleasant scenes, $Fs(1,14)>6.314$, $ps<0.025$, $\eta_p^2s > 0.31$.

Additionally, a main effect of Band was observed, $F(4,56)= 9.39$, $p<.001$, $\eta_p^2=.40$. Following this main effect, lower ratings for pictures in the lowest and highest spatial frequency bands compared with all others were found – $Fs(1,14)>6.51$, $ps<.023$, $\eta_p^2s>.32$ - and higher ratings for pictures in the lowest than in the highest band, $F(1,14)=8.16$, $p=.013$, $\eta_p^2=.37$. Focusing on the effects of identification accuracy on arousal ratings, the interaction between Content and Accuracy was observed, $F(2,28)=12.27$, $p<.001$, $\eta_p^2=.47$. Following this effect, a main effect of the Content was analyzed in accurate and non-accurate identification, showing no main effect of Content for non-accurate identification, $F(2,28)=2.15$, $p=.135$, $\eta_p^2=.13$. While, it was observed for accurate identification – $F(2,28)=13.19$, $p<.001$, $\eta_p^2p=.49$ – with higher arousal ratings for pleasant and unpleasant compared with neutral scenes – $Fs(1,14)>11.46$, $ps<.004$, $\eta_p^2s>.45$ – and no significant difference between ratings for pleasant and unpleasant scenes – $F(1,14)=3.87$, $p=.069$, $\eta_p^2=.22$. No significant three-way interaction between Content, Accuracy, and Band was observed in accurate description as shown in Figure 10 – $F(2,28)=.99$, $p=.386$, $\eta_p^2 =.07$.

Figure 10

SAM ratings of arousal for pleasant, neutral, and unpleasant pictures as a function of the five spatial frequency bands when scene identification was achieved



Note. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005). The figure is from the article by Mastria et al. (2024).

2.4.3 Discussion

The results of this study indicate that participants showed better identification of images in the intermediate bands compared to the extreme bands. Identification was greater when a low-pass filter was applied compared to a high-pass filter. Additionally, emotional modulation of arousal was observed only when the images were correctly identified, despite the application of the filter. Arousal modulation was greater in the lowest band than in the higher bands. However, the lowest and highest spatial frequency bands did not affect the accuracy and content. The results suggest that neither low nor high spatial frequencies alone contain the essential features needed to trigger an emotional response. Instead, an accurate understanding of the content is necessary for such a reaction to occur.

For Experiment 2, we used the low-pass filter (i.e, blurry stimuli as degraded stimuli) like De Cesarei and Codispoti (2008, 2011, 2013) since low-pass filtered images may be more ecologically valid in the context of rapid image recognition, as global spatial features – which remain intact after applying a low-pass filter –are typically more prominent in natural visual environments than fine-grained details, which are preserved by high-pass filtering (Quan Van Le et al., 2013).

2.5 Experiment 2 - Emotional interference

The present research studies whether cognitive control is activated to inhibit the attentional capture of distractors. If emotional interference is reduced following emotional distractors compared to neutral ones (Zeng et al., 2017), this would suggest that emotional stimuli activate cognitive control similarly to incongruent stimuli (i.e., the CSE; Gratton et al., 1992). However, it is also possible that arousing images may not modulate cognitive control, as observed by Dignath et al. (2017) and De Cesarei et al. (2023). Additionally, previous research has shown that degraded images can still elicit attentional capture of emotional responses (De Cesarei and Codispoti, 2008). Repeated degradation levels of previous emotional stimuli could influence attentional capture, as the recent model by Frings et al. (2020) proposes that repetition of stimulus characteristics may modulate cognitive control, resulting in a greater reduction of interference effects during stimulus repetition. Hence, the second aim was to explore whether a potential reduction in interference could be influenced by the repetition of the sensory-level characteristic of the distractors –

blurriness (i.e., low-pass filter). If all image features, including sensory/perceptual ones, contribute to cognitive control activation, we might expect a greater reduction in interference following emotional distractors when the image degradation level is repeated compared to when it is not (Frings et al., 2020). Alternatively, it is possible that degradation level repetition may not modulate interference reduction.

2.5.1 Method

2.5.1.1 Participants

Forty-three participants took part in the present study. Three participants were excluded due to an accuracy lower than 60%. Hence, the final sample size was forty participants. The experimental protocol conforms to the Declaration of Helsinki and was approved by the Ethics Committee of the University of Bologna. A power analysis was conducted using R (package pwrss; Bulus, 2023) to determine the required sample size for the four-way interaction of interest (Current Emotion x Previous Emotional x Filter x Repetition of Filter). The parameters used were α = 0.05, power = 0.80, partial eta squared (n_p^2) = 0.1 (Cohen, 1988), and a correlation among repeated measures of 0.24. The analysis indicated a minimum required sample size of 20 participants.

2.5.1.2 Stimuli

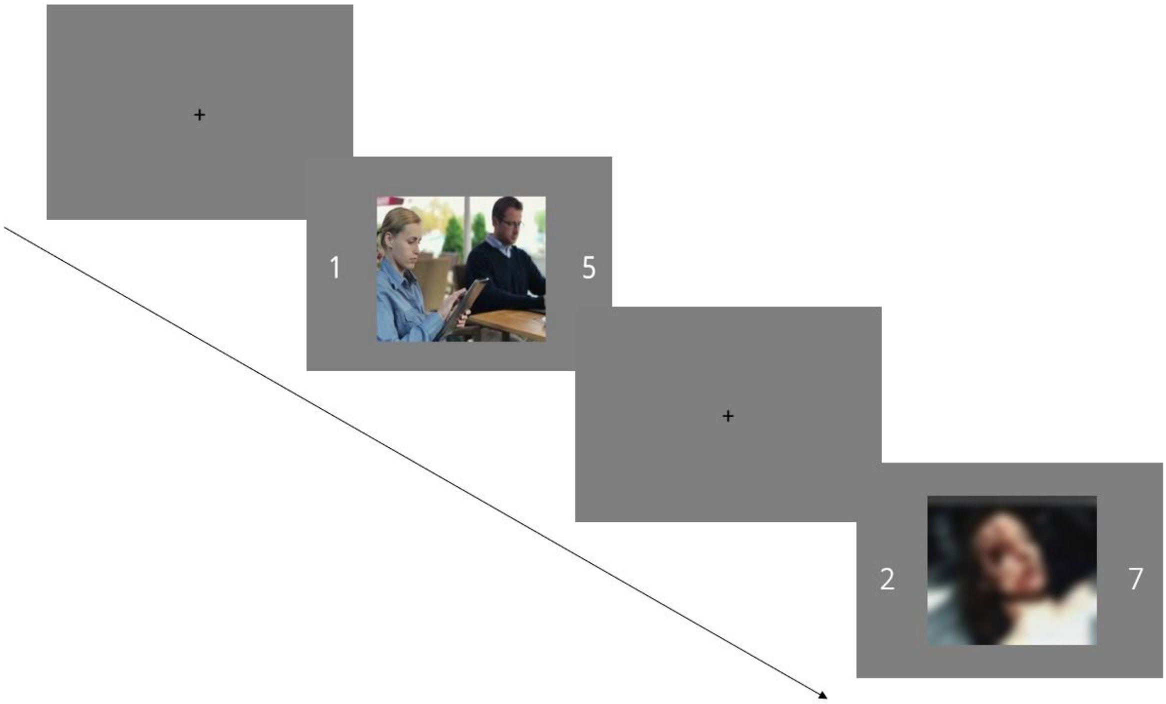
As for the target stimuli, digits from 1 to 9 were used. Regarding the distractor-images, 296 images were selected from the International Affective Picture System (IAPS; Lang et al., 2008) and Internet. The image dataset involved 148 pictures arousing (unpleasant and pleasant) and 148 neutral natural scenes. The images were presented in the dataset in both the intact and filtered versions. Each participant viewed either an image in the intact version or in the low-pass filtered version. Four additional pictures (2 intact and neutral and 2 filtered and emotional pictures) were selected to be used only in the practice phase.

2.5.1.3 Procedure

The experiment was conducted online via the Jatos platform. Before the experiment, 4 practice trials were presented to familiarize participants with the procedure. Each trial began with a fixation point lasting 500 ms, followed by a pair of numbers along with an emotional or neutral image shown between the numbers for 150 ms. Finally, a blank screen appeared for 3000 ms. An example of the experimental procedure is shown in Figure 11. The participant was required to categorize the pair of numbers based on whether both were either even or odd (i.e., having the same parity) or whether they had different parity (i.e., one even and one odd), ignoring the image that could be intact or filtered presented between numbers. The keys to be pressed for the response were Z and M, and the response key was counterbalanced across participants. Two blocks of 148 trials each were presented. As a constraint, it was decided not to present two numbers that were visually similar in the same pair (i.e., 3-8, 6-9, 1-7), no repetition of numbers within the same pair, and no numbers differing by only one digit from the other number in the pair. Additionally, no more than 6 consecutive trials with the same emotional content (i.e., emotional or neutral) were repeated, no more than 6 consecutive trials with alternating emotional content were included, no more than 6 consecutive trials with the same degradation level were repeated, and no more than 7 consecutive trials with different degradation levels were present. The total duration of the experiment was about 30 minutes.

Figure 11

An example of a trial procedure in which an intact neutral image is shown, followed by a blurred unpleasant emotional image



2.5.1.4 Analysis

Practice trials, trials that followed an error or in which an inaccurate response was given, the first trial of each block, and trials with RTs exceeding 2.5 standard deviations (SD) from the mean RTs were excluded from the RT analyses. Mean RT data were analyzed with repeated-measures ANOVA, with the following within-subject factors: Current Emotion (2 levels: Emotional and Neutral), Previous Emotion (2 levels: Previous Emotional and Previous Neutral), Filter (2: Intact and Filtered), Repetition of Filter (2 levels: Changed and Repeated). Huynh-Feldt correction was used when appropriate. The partial eta squared statistic (η_p^2) was calculated and reported.

2.5.2 Results

A main effect of Current Emotion was observed – $F(1,39)= 13.249$, $p=.001$, $\eta_p^2=.254$ – with slower responses when the distractors were emotional pictures compared to neutral pictures (M= 1195.042 ms, SD=260.378, M=1158.252 ms, SD=234.9418; respectively), but a main effect of the Previous Emotion was not significant, $F(1,39)= 1.176$, $p=.285$, $\eta_p^2=.029$. A significant main effect of Filter was found – $F(1,39)= 5.667$, $p=.022$, $\eta_p^2=.127$ – with slower responses during Intact picture distractors compared to Filtered ones: (M= 1186.554 ms, SD=258.0119, M= 1165.603 ms, SD=236.3142; respectively). Additionally, the Repetition of Filter was significant – $F(1,39)= 5.442$, $p=.025$, $\eta_p^2=.122$ – with faster responses when the filter was Repeated compared to when it was Changed (M=1167.381 ms, SD=242.254, M= 1183.676 ms, SD=251.927; respectively).

The two-way interaction between Current Emotion and Repetition of Filter was significant, $F(1,39)= 5.386$, $p=.026$, $n_p^2=.121$ – as shown in Figure 12. Following this interaction, we separately analyzed the main effects of Current Emotion when the filter was Repeated and when it was Changed across trials. A main effect of Current Emotion was observed only during Repeated Filter – $F(1,39)=17.994$, $p<.001$, $n_p^2=.316$ – with slower responses for emotional distractors (M = 1194.7820 ms, SD = 252.670) compared to neutral ones (M = 1141.337 ms, SD = 237.693). Instead, a main effect of Current Emotion was not significant during Changed Filter – $F(1,39)=1.802$, $p=.187$, $\eta_p^2=.044$.

The two-way interaction between Current Emotion and Filter was not significant, $F(1,39)=.982$, $p=.328$, $\eta_p^2=.025$.

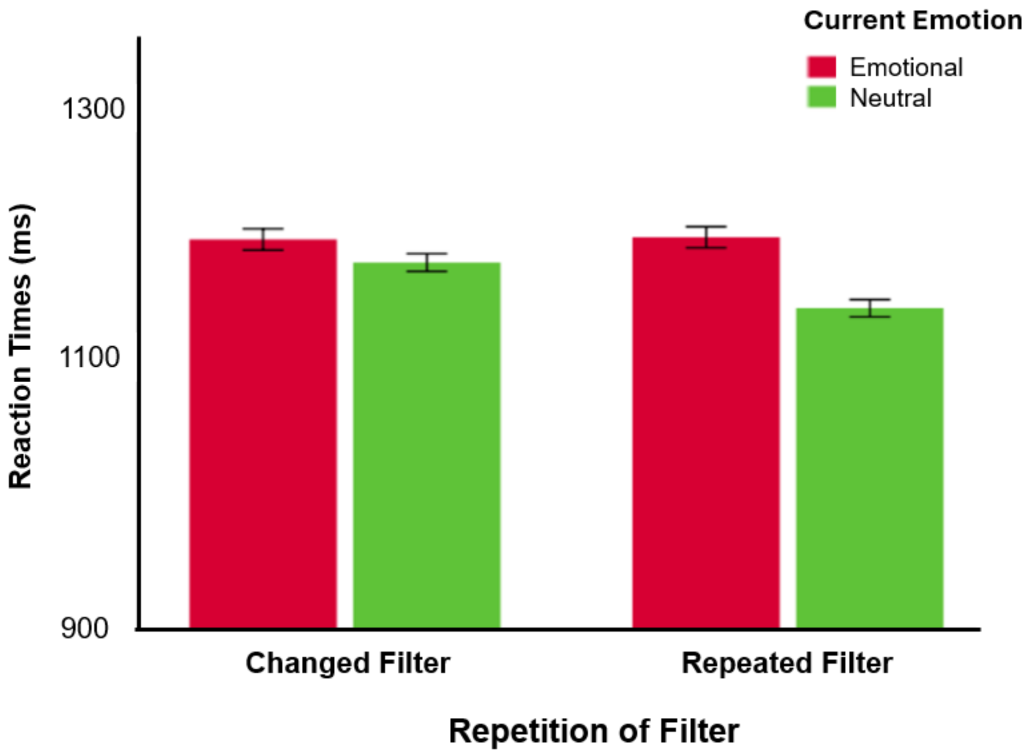
The two-way interaction between Current Emotion and Previous Emotion was significant, $F(1,39)= 4.150$, $p=.048$, $\eta_p^2=.096$. Following this interaction, slower responses were observed in trials with emotional distractors compared to trials with neutral distractors when they were preceded by trials with emotional distractors, $F(1,39)=17.076$, $p<.001$, $\eta_p^2=.305$. The trials with emotional distractors were associated with slower responses when preceded by trials with emotional distractors compared to when preceded by trials with neutral distractors, $F(1,39)=5.672$, $p=.022$, $\eta_p^2=.127$.

The three-way interaction between Previous Emotion, Filter and Repetition of Filter was found, $F(1,39)=5.314$, $p=.027$, $\eta_p^2=.120$. Following this effect, we analyzed the interaction between Previous Emotion and Filter in the Changed and Repeated conditions separately; it was not significant in either condition ($Fs \leq 2.486$, $ps \geq .123$, $\eta_p^2 s \leq .060$).

Finally, the interaction between Current Emotion, Previous Emotion and Repetition of Filter was not significant – $F(1,39)=.021$, $p=.887$, $\eta_p^2=.001$.

Figure 12

Mean RT data for current Emotion in Repeated and Changed Filters



Note. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005).

2.6 Discussion

In the current chapter, we studied whether cognitive control could be activated to counteract the interference caused by the attentional capture of emotional pictures during a parity categorization task. Notably, we studied whether previous emotional distractors could modulate the interference effect in the next trials compared to previous neutral distractor images. To this end, we replicated the paradigm used by Codispoti et al. (2016), in which participants were asked to quickly categorize two digits as either having the same parity (both odd or both even) or different parity (one even and one odd). On each trial, emotional or neutral pictures were presented between the two digits, and participants were instructed to ignore them.

The present study found slower responses during trials with emotional distractors compared to neutral distractors, suggesting an interference effect caused by emotional stimuli as observed in previous research (Bradley et al., 1996, 1999; Calvo and Nummenmaa, 2007; Okon-Singer et al., 2007; Codispoti et al., 2016). The attentional capture did not vary based on the level of image degradation, as found in the study by De Cesarei and Codispoti (2008). This result shows the intrinsic relevance of emotional stimuli, which can capture attentional resources even when the stimuli are slightly blurred.

Additionally, we might expect a reduction in emotional interference in the next trial with emotional distractors, as cognitive control could engage in suppressing the attentional capture caused by these distractors (Zeng et al., 2017), similar to what is observed in incongruent conditions (CSE; Gratton et al., 1992). Conversely, based on previous studies (Dignath et al., 2017; De Cesarei et al., 2023, Brown et al., 2014), we could also hypothesize that arousal images might not influence cognitive control. In line with these last studies, the modulation of previous emotion on the current emotional interference does not reflect the activation of cognitive control. In that case, we should have observed a pattern opposite to our results: The conflict caused by the previous emotional distractor should have activated cognitive control, leading to improved performance in the next trial; specifically, a reduction in the interference effect. One reason we may not observe a modulation of emotional interference by cognitive control, unlike in the study by Zeng et al. (2017), could be that their study used emotional stimuli as the target context in the Flanker task, while in our study, emotional stimuli served as distractors. This discrepancy in results may be due to emotional interference triggering cognitive control when emotional stimuli were targets rather than distractors. The arousal from emotional stimuli could enhance the association between task sets and task-relevant information when the stimuli are task-relevant.

The second aim of the present chapter was to study whether the repetition of features of the episodic representation that modulates cognitive control (Frings et al., 2020) could include sensory/perceptual features of the stimulus. We observed that attentional capture by emotional distractors was greater when the level of image degradation was repeated from one trial to the next, compared to when it changed. This effect can be explained by the repetition of the same condition of stimulus – either intact or blurred pictures – which reinforces perceptual/sensory features and may lead to the formation of a perceptual set – the mental predisposition to focus on certain features of sensory information while ignoring others (Biggs et al., 2015; Schyns and Oliva, 1999). This repeated exposure led to faster responses to the neutral distractors compared to conditions where the filter changed. A different pattern was observed during emotional distractors (i.e., no modulation by the repetition of the filter), suggesting that their relevance continues to capture attention. The influence of the repetition of the previous condition on the current condition could be explained by the phenomenon of the perceptual set (Biggs et al., 2015) rather than by the model proposed by Frings et al. (2020). An alternative interpretation could be the serial dependence effect (Fischer and Whitney, 2014). Unlike the perceptual set, which stems from expectations and past experiences, the effect of serial dependence reflects a temporal effect on visual perception, where the perception of the current stimulus is modulated by that of previous events, leading to a continuous and stable perceptual flow over time (Manassi et al., 2023), which can be observed in neutral distractors in the present experiment.

Finally, our findings showed that the previous condition modulated the current condition, but this modulation was not related to cognitive control since no reduction in the attentional capture of emotional stimuli was observed after the presentation of emotional stimuli compared to after the presentation of neutral stimuli. In fact, the activation of cognitive control caused by the arousal of emotional stimuli should have reduced the attentional capture caused by emotional distractors.

Chapter 3: Cognitive control and lying

3.1 Conflict caused by dishonest responses

Competing action plans generate internal conflict, prompting the need for control adjustments to prevent or manage similar conflicts in the future (Botvinick et al., 2001). An example of conflict is dishonest behavior, where individuals must override the activated truthful response in favor of a deceptive one (Duran et al., 2010; Walczyk et al., 2003). The initial activation of the truthful response can be an integral part of cognitive processing during a dishonest response. According to the Two-Step Hypothesis of Lying (Seymour, 1977), producing a dishonest response involves two stages: first, the truth is activated, and second, the lie is manipulated and formulated. In the initial phase, the individual recalls truthful information. Then, in the second phase, the person intentionally distorts, omits, or alters the facts to generate the lie. Hence, while generating a truthful response requires only a single cognitive step, constructing a lie demands two steps. This additional phase could contribute to the greater cognitive effort associated with lying (Seymour, 1977). The study by Debey et al. (2014) provided evidence for this theory. In an experiment with 20 yes/no questions, some questions included distractors designed to encourage either a truthful or deceptive response. The authors found that participants lied more quickly and accurately when truth-facilitating distractors were present compared to lie-facilitating distractors. They concluded that these truth-based distractors aid truth activation, assisting in constructing a believable lie.

Lying – whether by reporting, denying, distorting, or omitting the truth – is a fundamental aspect of human communication (Bavelas et al., 1990). During dishonest responses, a response monitoring process may be activated, leading to slower responses in dishonest conditions compared to honest ones – "intention effect" (Foerster et al., 2017, 2018). The monitoring process activated by dishonest responses may persist even after the response has been executed (Foerster, 2017, 2018, 2019, 2023). For example, in the study by Foerster et al. (2023) participants had to respond either honestly or dishonestly to yes/no questions about their daily activities – Intention task. After their response, there was a Tone task in which participants had to classify the pitch of a tone. Results showed that dishonest responses were slower than honest ones, and this effect propagated to the following Tone task: Responses to the Tone task were slower if a dishonest response to the Intention task had previously been given compared to an honest response (Foerster, 2023). Hence, the monitoring for dishonest responses could extend beyond mere execution, potentially to assess the successful completion of the dishonest response. However, a slowdown in responses was not always observed after responding dishonestly compared to honestly.

Over the years, the demand for deception detection has steadily increased, particularly in more stringent conditions such as courts. As a result, there has been a growing emphasis on developing detection methods that are both highly effective and precise. Several studies have drawn on the premise that a guilty individual knows and recognizes specific crime-related details that would be unfamiliar to an innocent person (Ben-Shakhar, 2016). Hence, guilty individuals are expected to respond differently when presented with crime-related details compared to neutral or irrelevant information, whereas innocent individuals should not display such a distinction in their responses (Verschuere et al., 2011). This principle forms the foundation of the Concealed Information Test (CIT; Lykken, 1959), which seeks to differentiate between concealed, crime-related knowledge and openly disclosed information. The CIT assesses physiological responses, such as arousal, when individuals are exposed to specific details of a crime that only the guilty person would recognize. During the CIT, a series of stimuli are presented to the participants, with only one stimulus being directly linked to the crime. For instance, in response to the question "Which weapon was used in the crime?" several options might be provided, such as "knife, gun, etc.". The guilty individual is expected to display a noticeable physiological response – such as increased skin conductance – when confronted with the actual crime-related detail. This reaction occurs because the guilty person recognizes the detail, even if they attempt to conceal it. On the other hand, an innocent person, unaware of the specifics, should not exhibit a significant response to any option. The difference in physiological responses between a guilty and innocent person thus serves as a potential marker of concealed knowledge. While the CIT is generally regarded as a reliable tool for detecting deception, its effectiveness is contingent on the availability of specific, crime-related details to test. However, the validity of skin conductance response as a measure has some limitations. One of them is that it is influenced by considerable individual variability, meaning that some people do not exhibit a measurable skin conductance at all – "non-responders" (Verschuere et al., 2010). Addionally, it is frequent to observe the habituation phenomenon: The physiological response diminishes after repeated exposures to the same stimuli. Due to these limitations, there has been a growing interest in exploring the potential of reaction time (RT) as a more reliable alternative. Reaction time-based tests not only bypass some of the issues associated with physiological responses, but they are also cost-effective and quick to administer (Verschuere et al., 2010; Suchotzki et al., 2017). In Reaction Time Concealed Information Tests (RT-CIT), participants are instructed to conceal specific details (i.e., "probes"). These probes are information (e.g., an object or word) that the participant is deliberately trying to hide. Alongside these probes, two other types of stimuli are presented: "target" stimuli, which are already known to the participant, and "irrelevant" stimuli, which are neutral and hold no significance because the participant has not encountered them before. As shown in Table 1, both target and irrelevant stimuli are associated with an honest response from the participant. However, the rationale of the RT-CIT is that when participants see the probe, they take longer to respond compared to the irrelevant stimuli. This is because recognizing the probe creates a cognitive conflict: The participant has to actively suppress their recognition of the probe, resulting in a slower reaction time. This delay is not present when responding to irrelevant stimuli, as these do not trigger the same internal recognition or conflict (; Suchotzki et al., 2017; Verschuere et al., 2010; klein Selle et al., 2023). For example, in a scenario where a participant is asked to conceal the knowledge of a specific weapon used in a crime (e.g., a knife), a series of images are shown, including the knife (i.e., the probe), alongside objects never seen before (i.e., the irrelevant stimuli) and objects previously seen but not related to crime (i.e., the target). Varga et al. (2015) observed that the response to the target items is slow for reasons unrelated to deceptive responses. In the literature, the differences in response times between dishonest and irrelevant conditions are primarily compared to detecting the intention effect.

Table 1

RT-CIT task used in the literature

RT- CIT label	Expected response	Lying condition	Real response
Irrelevant	Do not Know	Honest	Do not Know
Probe	Do not Know	Dishonest	Know
Target	Know	Honest	Know

If the participant takes longer to respond to the image of the knife compared to the irrelevant stimuli, it suggests they recognize it as related to the crime, even if they are trying to conceal this knowledge. This slower reaction time becomes a marker for detecting concealed information. The slowdown in response times could be due to the monitoring of dishonest responses (Foerster, 2017, 2018, 2019, 2023). It would be interesting to study whether this monitoring process persists after a dishonest response in the CIT paradigm, as observed in the paradigm by Foerster et al. (2023). Moreover, the CIT may better represent a context in which an interrogation occurs than the Intention-Tone task sequence of Foerster et al. (2023). Additionally, the RT-CIT measures pure cognitive conflict related to the recognition of hidden information, making it a more direct and straightforward method for detecting deception.

3.2 Lying and memory

The conflict between the initial tendency to give an honest response and the need to generate a dishonest one creates interference in executing the deceptive response (Geven et al., 2021; Noordraven and Verschuere, 2013; Suchotzki et al., 2017; klein Selle et al., 2023; Verschuere et al., 2010; Foerster et al., 2017; 2018). This interference may, in turn, influence the consolidation of memory related to the dishonest response.

Some studies have examined whether a previous false belief – that something never occurred – affects later memory for that false belief. Specifically, Veira and Lane (2013) found that participants had a poor memory for having falsely denied seeing a studied item. Additionally, Otgaar et al. (2014, 2016) demonstrated that falsely denying detailed discussion with the experimenter, when in fact they had, led to memory distortions. For example, Otgaar et al. (2014) showed a video to three groups of children and adults, and then assessed their memory of the video. In the "cued recall" condition, participants answered both true and false event-related questions and had the option to choose not to respond if they did not know the response. In the "forced confabulation" group, participants received the same set of questions but were required to respond to all of them even when they did not know the answer. Finally, in the "false denial" group, participants were instructed to falsely deny the answer to every question. One week later, participants took a memory test about the video. Forced confabulation led to false memories only in the youngest group, while false denials caused both children and adults to falsely claim that they had not discussed specific details of the videos with the experimenter. False denials may impair source monitoring, as repeatedly denying details can degrade the memory of the original event (Otgar et al., 2014). According to the Source Monitoring Framework (SMF; Johnson et al., 1993), lies typically require more cognitive effort, such as imagination, compared to genuine memories. However, when individuals falsely deny event details, their memory representations could be insufficiently processed, resulting in a weakened recall of those details (Otgaar et al., 2016). When participants are instructed to deny something, they may comply with the instructions without fully processing the specific details involved. This lack of cognitive engagement with the denied information may result in poor memory retention. These findings have legal implications; for instance, in sexual abuse cases, where victims are frequently interviewed multiple times. In criminal investigations, the phenomenon of incorrect forgetting is particularly concerning, as the gradual erosion of memory details can be misconstrued as inconsistencies, potentially damaging the victim's credibility in court (Loftus and Davis, 2006). These findings suggest the need to further study how repeated questions, and false denials can affect memory recall, especially in sensitive legal contexts.

On the other hand, the increased cognitive effort required for generating a dishonest response may offer some advantages in memory retention compared to honest responses (Besken, 2018). This aligns with findings from Stroop-like tasks, where participants tend to have better memory for targets presented alongside incongruent distractors than with congruent ones (Krebs et al., 2015; Rosner et al., 2015). The conflict caused by incongruent distractors enhances attention to the relevant aspects of the task (Botvinick et al., 2001), which can lead to improved encoding and subsequently better recall of the target stimuli. This suggests that cognitive conflict, whether in deception or attentional tasks, may play a role in boosting memory performance. In addition, denying an object requires both recalling the memory of having seen the object and remembering to provide a dishonest response for it. This dual retrieval may lead to stronger consolidation and, consequently, improved memory retention due to the deeper level of cognitive processing involved (Craik and Lockart, 1972; Besken, 2018).

3.3 Research questions and hypotheses

Previous studies have observed that conflict arising from the tendency to respond truthfully and the need to generate a lie led to interference (Foerster, 2017, 2018, 2019, 2023). Since this conflict may activate cognitive control, improving performance in subsequent trials (Botvinck et al., 2001), and Foerster et al. (2023) observed a monitoring process even after the dishonest response, it raises the question: Can the conflict generated by lying modulate the response following the lie?

Furthermore, given that prior research (Veira and Lane, 2013; Otgaar et al., 2014, 2016) has found that the conflict associated with lying affects memory related to the lie, we wondered whether this conflict is limited to influencing the immediate moment or if it also impacts the memory. To investigate this, the current study involves two experimental sessions conducted one week apart.

The aim of the first session is to study whether the deception monitoring persists even after the execution of the dishonest response itself, in an RT-CIT paradigm. To this end, participants were shown videos of real-world apartments, with a cover story that one of the apartments had been the scene of a theft, while the other was for a rental service video. In the RT-CIT paradigm, participants had to categorize objects belonging to the two apartments and new objects as old and new, lying about having seen the items of the theft apartment while responding honestly to the other items. We could find slower reaction times for dishonest responses compared to honest responses (i.e., intention effect), as observed in the literature (Geven et al., 2021; Noordraven and Verschuere, 2013; Suchotzki et al., 2017; klein Selle et al., 2023; Verschuere et al., 2010). The most relevant aim of the first session was to study the propagation of the intention effect in the next trials. According to the study by Foerster et al. (2023), trials following a deception could be associated with slower responses compared to trials after an honest response, since the monitoring of dishonest responses could persist after lying. In this case, we can expect to observe slower responses in trials preceded by dishonest rather than honest responses. However, in the study by Foerster et al. (2023), the task requirements changed from one trial to another (from Intention task to Tone task), whereas, in the present study, the task requirement is always the same across trials. Therefore, we might expect a different pattern of results compared to the study by Foerster et al. (2023): No propagation of intention effect to following trials. As suggested by Pfeuffer et al. (2019), performance benefits from repeating the previous context, which is the same rule task across trials in our study, occur during the repetition of both honest and dishonest responses. Finally, we might expect a reduction in the intention effect after dishonest responses compared to honest responses, as the activation of cognitive control during the conflict could persist after the response, thereby reducing the interference effect in the subsequent trial, similar to what occurs in tasks where conflict arises from incongruent trials (e.g., the CSE model; Gratton et al., 1992).

The aim of the second session is to study the effects of lies on object memory. Specifically, the effect of false denial during an interrogation. A week after the first experiment, participants were shown the same pictures from the previous week along with new images, and they were asked to categorize the pictures as either novel or old. On one hand, if denying decreases memory accuracy, we could observe lower accuracy in the recognition of the stimuli that was in dishonest condition in the first session (Vieira and Lane, 2013). On the other hand, items in dishonest condition during the first session require retrieving both the memory of having seen an object and the memory that a dishonest response was given for that item. In this latter case, greater consolidation and a deeper level of processing could occur, leading to better memory (Craik and Lockart, 1972; Besken, 2018).

3.4 First session - Lying and cognitive control

3.4.1. Method

3.4.1.1. Participants

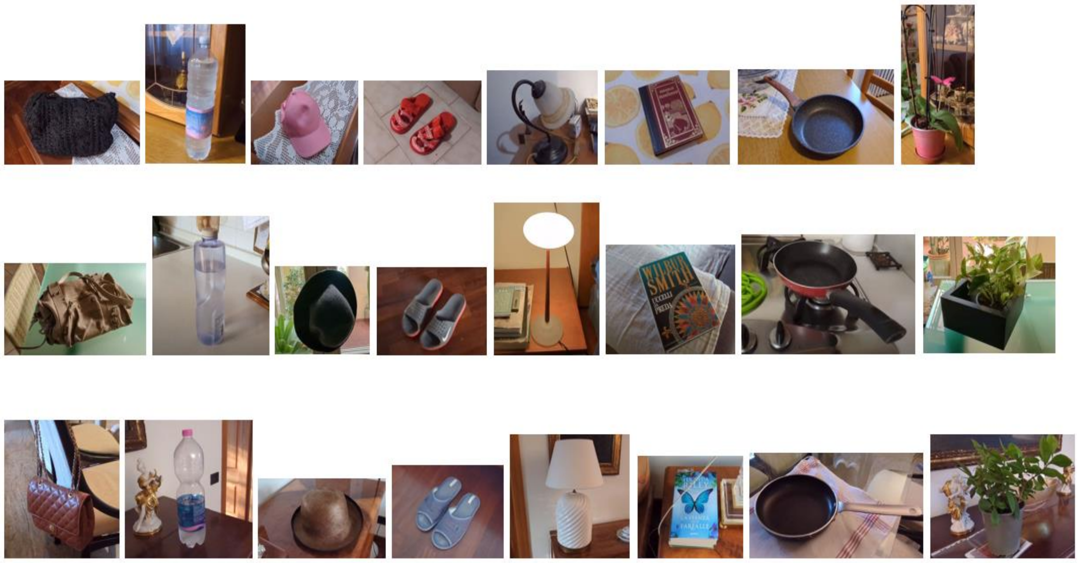
Sixty-seven participants with normal or corrected vision took part in the experiment. Four participants were excluded since one participant failed to comply with task instructions in the recognition (RT-CIT) task, and three participants achieved less than 60% accuracy in the training tasks. Therefore, data from 63 participants were analyzed (40 females, age M=22.484, SD=3.192). The experimental protocol conformed to the Declaration of Helsinki and was approved by the Ethical Committee of the University of Bologna. A power analysis was conducted using R (package pwrss; Bulus, 2023) to determine the required sample size based on the two-way interaction of interest (Current Condition x Previous Condition), a desired medium-large effect size (partial eta squared = 0.1; Cohen, 1988), 80% power, and a low correlation (r = 0.24) between repeated measures. The power analysis indicated that the required sample size to observe this interaction effect would be 13 participants.

3.4.1.2 Stimuli

In the learning phase, two videos of two different apartments were presented. The videos showed a living room and a bedroom, each lasting approximately 2 minutes. The videos were displayed in full screen (1280 x1024 pixels), subtending 20°30' horizontally and 16°20' vertically at a visual angle. During both the learning phase and the recognition (RT-CIT) phase, images of objects that appeared in the apartment videos were still shown. Additionally, objects from a third apartment that were not in the videos were shown as control stimuli. A total of 8 different objects were selected from each apartment, including a bag, bottle, hat, slippers, lamp, book, pot, and vase. Hence, there were 24 different images. Pictures were taken as still frames from each video to maximize the effects of context (Figure 13). The visual angle ranged from 16°41' to 16°56' horizontally and from 9°43' to 13°56' vertically.

Figure 13

Pictures of objects used in the experiment



3.4.1.3 Procedure

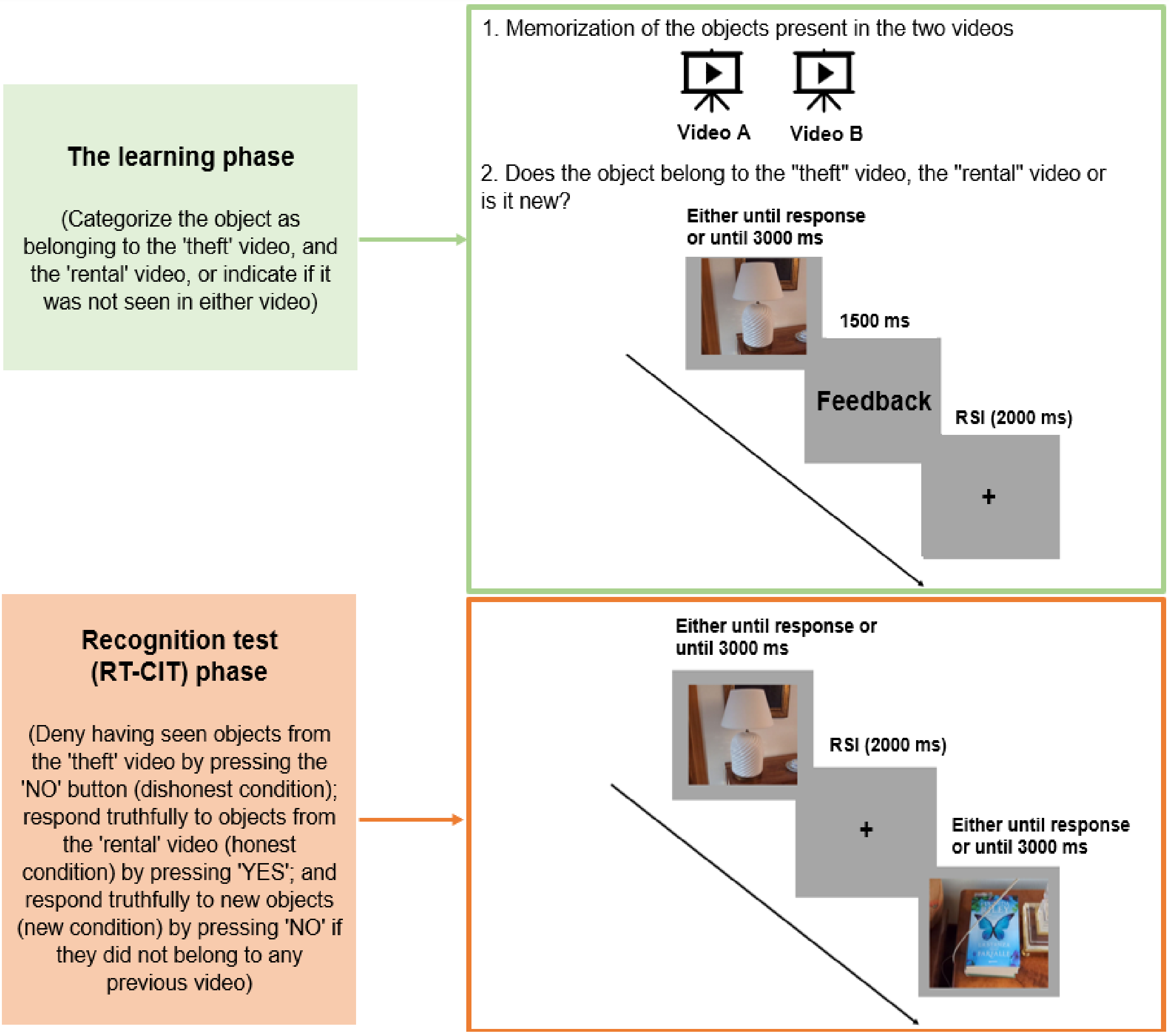
After filling out the informed consent form, the participant was accompanied to the experimental room where the illumination was 3 lux, measured using a diode-type digital luxmeter. The experiment consisted of two parts: two learning phases and a recognition test (RT-CIT) phase, as shown in Figure 14.

In the learning phase, participants watched videos of two apartments. For one video, they were told it represented a 'theft' condition, where the apartment had been filmed after a robbery, and they were asked to imagine being seen by a witness at the scene on the day of the theft. For the other video, labeled the 'rental' condition, participants were told the apartment had been filmed for a home rental advertisement, and they were asked to imagine themselves planning a vacation and discovering the apartment video on a rental website. After watching the two videos, participants were shown pictures of objects that belonged to either video, along with an additional 8 pictures from an apartment that had not been shown. They had to indicate whether each object belonged to the 'theft' video, the 'rental' video, or was not seen in either video. Each image was displayed until the participant responded (using the C, X, and Z keys on the QWERTY-it layout) or for a maximum of 3000 ms, followed by feedback for 1500 ms and a response-stimulus interval (RSI) of 2000 ms. There was a total of 24 trials, each containing 24 different images of 8 objects from each video. The images were presented in a pseudo-random sequence with the constraint that no more than 3 consecutive pictures came from the same video. To help participants better familiarize themselves with the apartments and objects, the procedure (video viewing followed by three-choice categorization tasks) was repeated twice (Verschuere et al., 2010). In the second recognition task, the order of the objects to be recognized varied from the first task. The presentation order of the videos and the association between videos and 'theft' or 'rental' conditions were counterbalanced across participants.

During the test phase, a recognition task (RT-CIT) was performed, though different terminology was used to describe the items. Objects that were never shown in the previous videos and are defined in the literature as "irrelevant" were referred to as "new". Objects that participants had to lie about, defined in the literature as "probe", were referred to as "dishonest". Finally, objects that participants had to respond to truthfully and are defined in the literature as "target" were referred to as "honest". Participants were reminded that a witness claimed to have seen them in the building where the theft occurred. To avoid suspicion, they were instructed to pretend they had never been in that building, especially in the specific apartment shown. Their task was to act as though they had never seen the objects from the apartment where the theft took place. Participants were instructed to deny having seen them by pressing the 'NO' button on the keyboard (dishonest condition), when objects from the 'theft' apartment video appeared. In contrast, participants were required to respond truthfully when objects from the 'rental' video were displayed (honest condition), indicating they had seen them before by pressing the 'YES' button on the keyboard. Finally, participants were instructed to respond truthfully when the objects were news (new condition), stating they had never seen them by pressing the 'NO' button on the keyboard. Each object was presented and repeated 10 times for a total of 240 trials. Each image was displayed either until the participant responded or for a maximum of 3000 ms, followed by a response-stimulus interval (RSI) of 2000 ms. An example of the procedure is shown in Figure 14. The 'YES' and 'NO' responses were assigned to the j and n keys on the QWERTY-it keyboard, and the assignment of response keys was counterbalanced across participants. Images were presented in pseudo-random sequences with specific constraints: no more than 3 consecutive trials could belong to the same condition (New, Dishonest, Honest), and no more than 5 consecutive trials with the same images. In both learning and recognition (RT-CIT) phases, participants were instructed to respond using the index finger of their dominant hand; their distance from the monitor was 94 cm. The experiment was conducted using E-Prime 2.0 Professional, and it lasted approximately 30 minutes.

Figure 14

Trial procedure of the experiment



3.4.1.4 Analysis

Only participants who achieved at least 60% accuracy in all three conditions (dishonest, honest, new) at the end of the learning phase were included in the analysis. Regarding Reaction Times (RTs), at the end of the learning phase, trials with incorrect responses, the first trial of each block, and those with RTs exceeding

2.5 standard deviations (SD) from the RT mean were excluded. The mean RT was analyzed using a repeated-measures ANOVA, with Current Condition (3 levels: New, Dishonest, Honest) as the within-subject factor.

In the recognition (RT-CIT) task, trials that followed an error, trials with an incorrect response, the first trial of each block, and those with RTs exceeding 2.5 SD from the mean RTs were also excluded. The mean RT was analyzed using repeated-measures ANOVA, with Current Condition (3 levels: New, Dishonest, Honest) and Previous Condition (3 levels: Previous New [PreNew], Previous Dishonest [PreDishonest], Previous Honest [PreHonest]) as within-subject factors. Then, we repeated the analysis without the level "Honest" in the Current Condition and "Previous Honest" in the Previous Condition. The Huynh-Feldt correction was applied when appropriate, and the partial eta squared statistic (n_p^2) was calculated and reported.

3.4.2 Results

3.4.2.1 Final learning task

3.4.2.1.1 Accuracy

A main effect of Current Condition was not significant, $F(2,124)=2.503$, $p=.086$, $\eta_p^{2=}.039$ (New condition: M=.955, SD= .088; Dishonest condition: M=.935, SD=.089; Honest condition: M=.921, SD= .093).

3.4.2.1.2 RTs

A main effect of Current Condition was significant, $F(2,124)=11.956$, $p<.001$, $\eta_p^{2=}.162$, with slower responses for dishonest conditions (M=1292.035 ms, SD=

255.470) compared with new conditions (M=1154.486 ms, SD=181.206), $F(1,62)=20.451$, $p<.001$, $\eta_p^{2=}.248$. Moreover, the honest conditions were associated with slower responses (M=1264.429 ms, SD=245.472) compared to new conditions, $F(1,62)=11.953$, $p=.001$, $\eta_p^{2=}.162$. However, there were no differences between honest and dishonest conditions: $F(1,62)=1.057$, $p=.308$, $\eta_p^{2=}.017$.

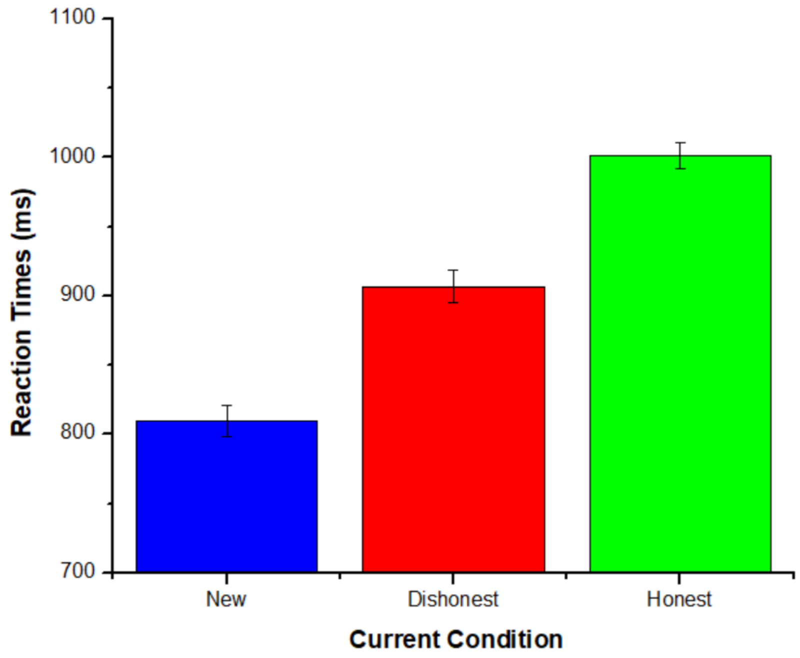
3.4.2.2 RT-CIT

3.4.2.2.1 Overall results

A main effect of the Current Condition was significant, $F(2,124)=78.496$, $p<.001$, $\eta_p^2= .559$, as shown in Figure 15. Following this main effect, slower responses were observed for dishonest conditions compared with new conditions, $F(1,62)=32.939$, $p<.001$, $\eta_p^2=.347$. Moreover, honest conditions were associated with slower responses compared with dishonest and new conditions; $F(1,62)=39.823$, $p<.001$, $\eta_p^2=.391$, $F(1,62)=196.745$, $p<.001$, $\eta_p^22= .760$, respectively.

Figure 15

Mean RT in Current Condition

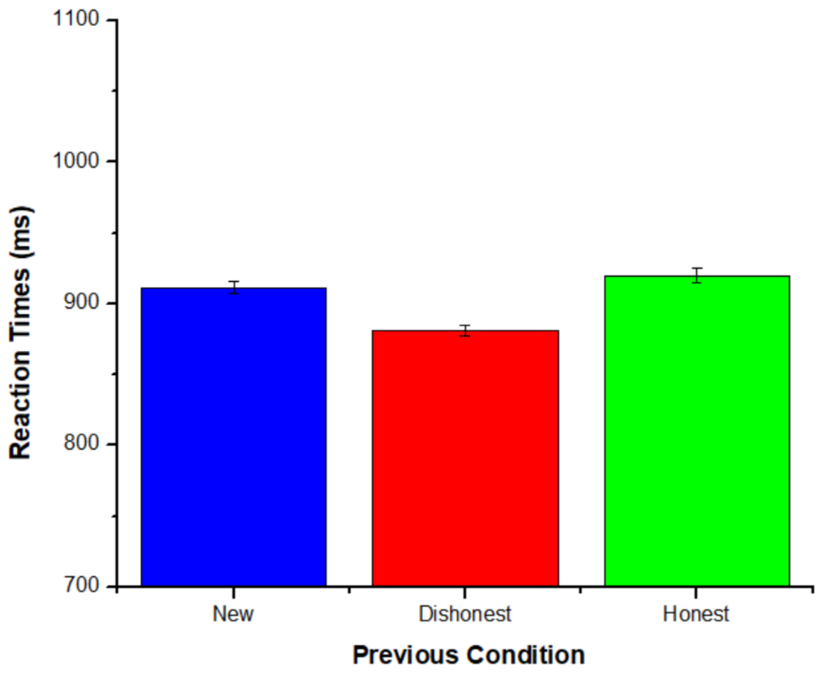


Note. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005)

A main effect of Previous Condition was significant, $F(2,124)=18.535$, $p<.001$, $\eta_p^2=.230$, as shown in Figure 16. Faster responses were observed for dishonest conditions compared with new and honest conditions; $F(1,62)=33.153$, $p<.001$, $\eta_p^2=.348$ and $F(1,62)=38.628$, $p<.001$, $\eta_p^2=.384$, respectively. Instead, no differences between the honest and new conditions were observed: $F(1,62)=1.509$, $p=.224$, $\eta_p^{2}=.024$.

Figure 16

Mean RT in Previous Condition

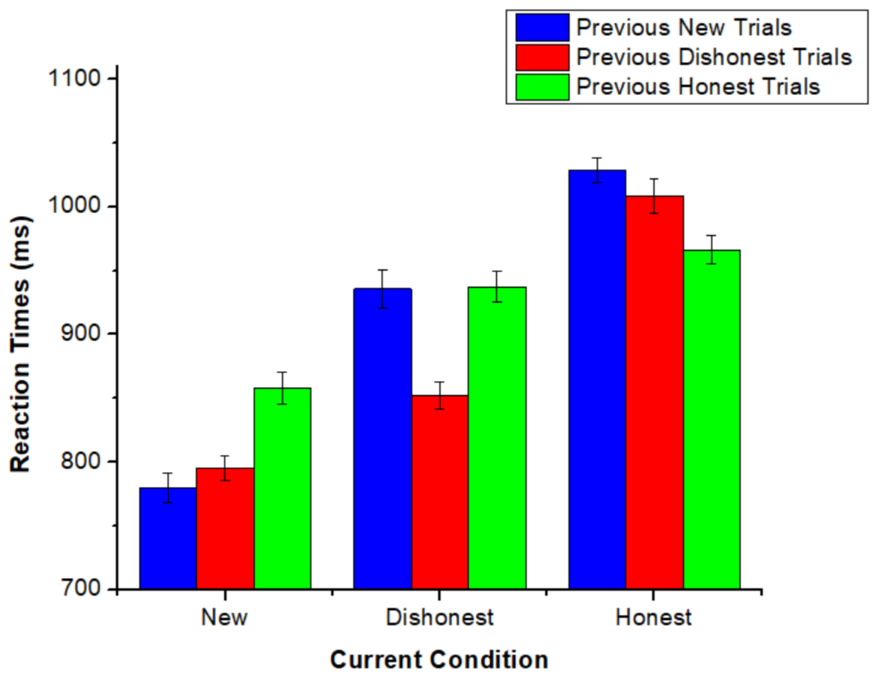


Note. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005).

The two-way interaction between Current and Previous Condition was significant, $F(4,248)=24.531$, $p<.001$, $\eta_p^2=.283$, as shown in Figure 17. Following this interaction, faster responses to new conditions were observed when they were preceded by new conditions rather than by dishonest and honest conditions, $F(1,62)=4.063$, $p=.048$, $\eta_p^2=.061$, $F(1,62)=42.696$, $p<.001$, $\eta_p^2=.408$; respectively. Additionally, new conditions were associated with slower RTs when they were preceded by honest conditions compared to when they were preceded by dishonest conditions; $F(1,62)=36.425$, $p<.001$, $\eta_p^2=.370$. Responses were faster during dishonest conditions when they were preceded by dishonest conditions rather than by new and honest conditions; $F(1,62)=63.611$, $p<.001$, $\eta_p^2=.506$, $F(1,62)=45.148$, $p<.001$, $\eta_p^2=.421$, respectively. Instead, no differences in dishonest conditions following honest and new conditions were observed, $F(1,62)=.010$, $p=.919$, $\eta_p^2=.000$. Finally, faster responses were observed in honest conditions when they were preceded by honest rather than dishonest conditions, $F(1,62)=7.682$, $p=.007$, $\eta_p^2=.110$. Additionally, honest conditions were associated with faster responses when they were preceded by honest rather than new conditions, $F(1,62)=22.399$, $p<.001$, $\eta_p^2=.265$. Honest conditions following the dishonest were not different from honest conditions preceded by new conditions, $F(1,62)=3.115$, $p=.082$, $\eta_p^2=.048$.

Figure 17

Mean RT data as a function of Previous and Current Condition



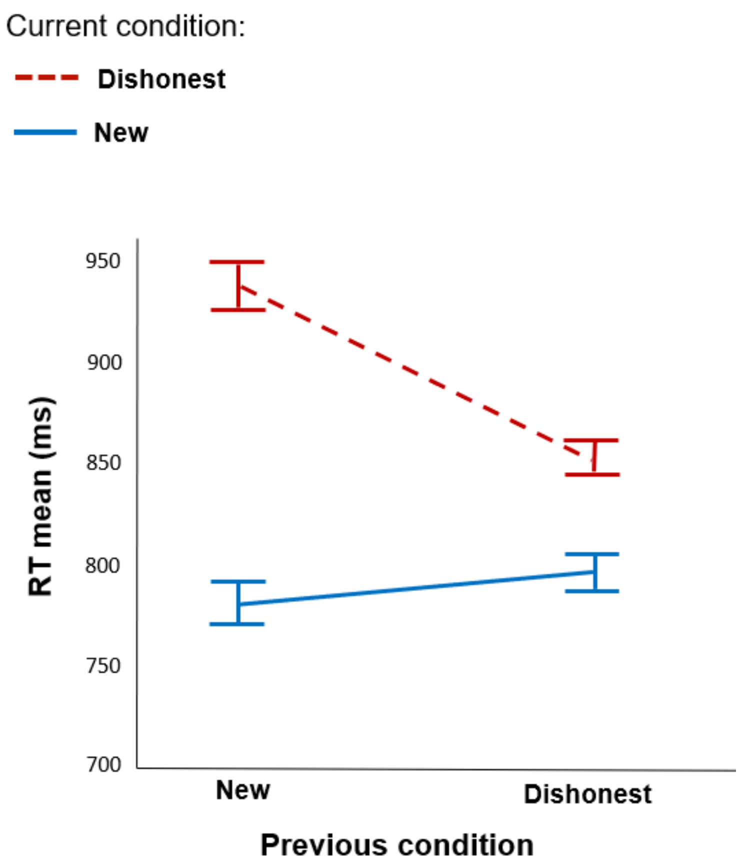
Note. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005).

3.4.2.2.2 Lying-related conflict results

The repeated analysis without the level “Honest” in the Current Condition and “Previous Honest” in the Previous Condition showed a main effect of Current Condition, $F(1,62)=38.711$, $p<.001$, $\eta_p^2=.384$. Slower responses were observed for dishonest conditions (M=906.741 ms, SD=146.709) compared with new conditions (M=809.891 ms, SD=139.176). A main effect of Previous Condition was significant, $F(1,62)=28.265$, $p<.001$, $\eta_p^2=.313$, with faster responses in trials following dishonest conditions (M=881.170 ms, SD=138.792) compared trials following new conditions (M=911.526 ms, SD=139.612). The two-way interaction between Current and Previous Condition was significant, $F(1,62)=59.421$, $p<.001$, $\eta_p^{2=}.489$, as shown in Figure 18. Following this interaction, slower responses to dishonest conditions compared to new ones were observed when they were preceded by new conditions, $F(1,62)=58.347$, $p<.001$, $\eta_p^{2=}.485$, and also when they were preceded by dishonest ones, $F(1,62)=12.900$, $p=.001$, $\eta_p^{2=}.172$. Faster responses to dishonest conditions were observed when they were preceded by dishonest conditions compared to new ones, $F(1,62)=63.611$, $p<.001$, $\eta_p^{2=}.506$. Slower responses to new conditions were observed when they were preceded by dishonest conditions compared to new ones, $F(1,62)=62$, $p=.048$, $\eta_p^{2=}.061$.

Figure 18

Mean RT data as a function of Previous and Current Condition



Note. Red (dashed) lines reflect the current dishonest conditions, and blue (solid) lines represent the current new conditions. Error bars reflect ±1 within-subject standard errors of the mean (Cousineau, 2005).

3.5 Second session - Lying and memory

3.5.1. Method

3.5.1.1. Participants

Fifty-five participants from the first session returned to complete the second session. Of the 55 individuals, one was excluded for accuracy less than 60% in the memory task, and two people were excluded due to low performance in the first session, which led to their exclusion from the analysis of the previous session. Therefore, a total of 52 participants were considered for the analyses (33 females, age M=22.5, SD=3.3). The experimental protocol conformed to the declaration of Helsinki and was approved by the Ethical Committee of the University of Bologna.

3.5.1.2 Material and stimuli

The same 16 pictures belonging to the “theft” and “rental” condition of the previous experiment were shown, plus additional 16 novel pictures.

3.5.1.3 Procedure

One week after the first session, participants returned to the laboratory to perform the memory test. They viewed the same 16 pictures from the “theft” and “rental” condition of the first experiment, and additional 16 pictures entirely new pictures that had not appeared in the videos or the categorization and CIT tasks. Participants had to distinguish the new stimuli from the old ones (items from “theft” and “rental” conditions of the previous experiment). Each picture was presented for a duration of up to 3000 ms followed by an inter-trial interval (ITI) of 2000 ms and another image. Each picture was repeated 4 times, for a total of 128 trials. The total duration of the session was approximately 30 minutes.

3.5.1.4 Analysis

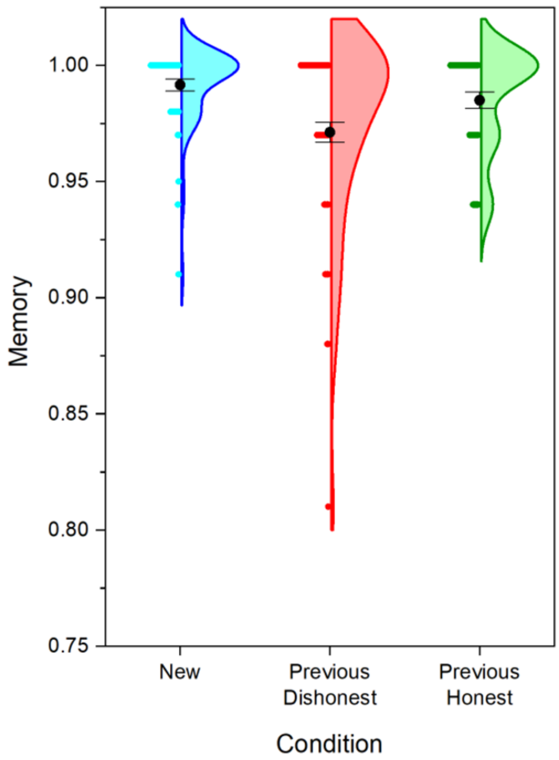
Only participants who achieved at least 60% accuracy in all three conditions ('theft,' 'rental,' 'new') during the categorization task were included in the analysis. The accuracy was examined with repeated-measures ANOVA, with Condition (three levels: New, Dishonest, Honest) as the within-subject factor. The Huynh–Feldt correction was applied when necessary. The partial eta squared statistic (n_p^2) was calculated and reported.

3.5.2 Results

A significant effect of Condition was observed on accuracy, $F(2, 102)=8.761$, $p=.001$, $\eta_p^2=.15$, as shown in Figure 19. Following this main effect, lower accuracy for stimuli that participants denied having seen (theft condition) was observed compared with new stimuli and objects they sincerely confirmed having seen (rental condition), $F(1, 51)=16.25$, $p<.001$, $\eta_p^2=.24$ and $F(1, 51)=5.16$, $p=.028$, $\eta_p^2=.092$, respectively. No differences between new and rental conditions were observed, $F(1, 51)=3.524$, $p=.066$, $\eta_p^2= .065$.

Figure 19

Accuracy in the memory task



Note. Black dots indicate the mean for each condition, and error bars reflect the within-participant standard error of the mean. Colored dots represent the average of individual participant for each condition, with violin plots illustrating the overall data distribution.

Moreover, we calculated the correlation between the accuracy of the first session and the accuracy of the second session to analyze the relationship between the CIT performance and the memory for CIT items after a week. Significant correlations were observed between CIT performances for dishonest and honest objects of the first session, and memory for new (“new”; r = .459 and r = .378, respectively) and previously dishonest (“theft”; r = .342 and r = .368, respectively). Negative correlation was observed between accuracy in the first session for “theft” and “rental” items, and memory difference between honest and dishonest objects (r = -.396 and r = -.313, respectively) showing higher memory difference for participants who had lowest accuracy in the first session.

3.6 Discussion

3.6.1 Lying and cognitive control

The aim of the first experiment was to study whether the monitoring of dishonest responses persisted even after the execution of the response. To this end, we used a RT-CIT paradigm where participants categorized items of the two videos, which were shown in the learning phase, and new items as “old” and “new” by responding honestly for the honest and new conditions and dishonestly for the theft condition. We observed an intention effect: Slower responses in dishonest conditions compared to honest ones in agreement with the literature (Geven et al., 2021; Noordraven and Verschuere, 2013; Suchotzki et al., 2017; klein Selle et al., 2023; Verschuere et al., 2010; Foerster et al., 2017; 2018). Longer reaction times suggest more monitoring process during dishonest responses compared to honest conditions (Foerster et al., 2017; 2018), possibly due to the interference between the initially and automatically honest response and the task-required dishonest response (Duran et al., 2010; Walczyk et al., 2003). Additionally, we observed faster responses after dishonest conditions compared to honest ones.

In our study, the repetition of the previous intentional response may have led to a priming effect (Bargh, 2014) – a phenomenon in which exposure to a stimulus influences the response to the next stimulus, resulting in better performance. We observed that when a condition was repeated in the next trial, response times were faster compared to when it was preceded by a different condition (Bargh, 2014; Hommel, 2004). These results were evident for the honest, dishonest, and new conditions, but the effect was more pronounced for the dishonest condition. This could be due to the retrieval of the previous control state activated during the dishonest responses. The same pattern could not be observed in Foerster et al. (2023), as the previous response was never repeated due to the use of a switch task paradigm. Furthermore, the analyses on the modulation of the previous condition in the responses of current trials – specifically the analyses without the honest condition (i.e., new vs. dishonest conditions) –showed that the interference effect caused by dishonest responses was reduced when the trials were preceded by dishonest conditions rather than by new ones. This sequential effect could indicate the activation of cognitive control that occurs during a conflict condition (i.e., dishonest conditions) leads to better performance in subsequent trials, as observed in the CSE phenomenon.

Our findings are different from the study by Foerster et al. (2023) since the authors observed slower responses after dishonest conditions compared to honest ones. Lying demands more cognitive resources than honest responses due to conflict situations which could activate cognitive control to monitor the responses (Botvinick et al., 2001). To ensure the dishonest response was executed correctly and/or to monitor its immediate consequences (Kunde et al., 2018; Wirth et al., 2018), the process of monitoring deception may continue even after the response has been made. The extended monitoring could result in longer reaction times after dishonest responses compared to trials following honest responses. The difference between our paradigm and that of Foerster et al. (2023) may have activated two different components of cognitive control. The present paradigm could activate cognitive stability, which refers to the ability to maintain focus and consistently engage in a task over time (Egner, 2023). This is because our task required participants to operate within a single, unchanging task set throughout the experiment, reinforcing steady attention and task adherence. In contrast, the paradigm used by Foerster et al. (2023) may have triggered cognitive flexibility, which is the capacity to switch between different tasks or strategies in response to changing demands. Their design required participants to alternate between Intention task and Tone task, encouraging mental flexibility and adaptability. Cognitive stability and cognitive flexibility are considered two independent but complementary aspects of cognitive control (Egner, 2023). Stability is crucial for tasks that require sustained attention, as it helps prevent interference from distracting conditions – such as the tendency to respond truthfully when one is required to lie, as seen in the present paradigm. On the other hand, flexibility allows individuals to adapt their behavior quickly when the task or environment changes, which is crucial in more dynamic or unpredictable situations. In addition, Pfeuffer et al. (2019) observed that the automatic retrieval of previous responses occurred only when the intentional context (i.e., to tell the truth or a lie) repeated across trials, but not when it switched.

3.6.2 Lying and memory

The second session aimed to investigate whether dishonest responses could affect the memory related to dishonest responses. The present results are consistent with the literature (Vieira and Lane, 2013) since we observed less accuracy for items that were in dishonest conditions in the first session, compared to objects that were in honest conditions in the first session. The lower memory for dishonest items in the first session compared with honest objects is due to the participants' low accuracy in the first session. This result cannot be due to a failure to recognize dishonest items in the first session since the accuracy was higher than for novel items. Lower accuracy for objects in dishonest conditions during the first session might be due to a conflict between an initial tendency towards honest and dishonest responses (Suchotzki et al., 2017; Verschuere et al., 2010, Foerster et al., 2023). This conflict may interfere with the consolidation of memory (Bjork and Bjork, 1992), since the honest response must be suppressed to generate the dishonest response. Moreover, errors during conflict related to dishonest conditions may have interfered with consolidation, leading to worse memory (Bridger and Mecklinger, 2014). Supporting this, we observed that those individuals who performed poorly during the dishonest responses were the same individuals who, after a week, showed a relative impairment for those items. These findings could be important from a judicial point of view, for example, in the case of victims who initially deny being abused and later need to recall events.

Future studies may investigate whether object memories concern the objects themselves or the context in which they are presented. We presented objects in their original context, but future experiments might extend these results by studying whether the lies affect memory for individual objects or also their context. Moreover, the next step could investigate the electrocortical response during the memory test of previously seen objects (i.e., to which participants lied or responded truthfully) and objects never seen before. The conflict between the natural inclination to respond truthfully and the effort required to produce a dishonest response may impair the encoding of information associated with the lie (Bridger and Mecklinger, 2014). This cognitive conflict can reduce the attention or resources available for properly encoding these items, leading to poorer recall of those details in a later memory test. For this reason, it would be interesting to study, in addition to the behavioral response, the so-called event-related potential (ERP) old/new effect, which is visible as a more positive ERP waveform for old items (i.e., studied items) compared to ERPs elicited by new items (Friedman and Johnson, 2000). Although the items participants lied about are old, we might expect that the item associated with a dishonest response in the first session could trigger an ERP response similar to that of new items. This is because the conflict created by lies may have interfered with the encoding of those items.

Discussion

The present thesis examines how cognitive control is modulated across different conflict contexts, as previous research indicates that levels of conflict differ in their functional characteristics (Becker et al., 2024). We investigated whether paradigms that induce conflict led to distinct modulations of cognitive control and whether this control manifests similarly across three different paradigms: semantic conflict (Picture Word Interference task – PWI), emotional conflict (induced by emotional images), and conflict arising from dishonest responses. Can different conflict contexts modulate the cognitive control response in the same ways?

Our results showed that cognitive control was activated during semantic interference and dishonest conditions. The semantic interference was studied in the first chapter, which focused on which repetition of the previous features from episodic representation – superordinate categorical vs./perceptual/sensory features – can modulate cognitive control, both at the behavioral and electrocortical levels. The Sequential Congruence Effect (CSE, Gratton et al., 1992) was used as an index of cognitive control. Regarding CSE mechanisms, recent models emphasized the role of learning in linking external stimuli to appropriate internal states (Egner, 2014; Abrahamse et al., 2016; Dignath et al., 2019; Verguts and Notebaert, 2008). Additionally, the Binding and Retrieval in Action Control (BRAC) model (Frings et al., 2020) claims that associations between perceptual/sensory stimulus features and motor actions can be formed in an episodic representation, along with the associations between contextual cues and internal attentional states and processing strategies. Any type of stimulus feature presented can be encoded, and if one of these features is re-presented in the subsequent event, the entire episodic representation will be reactivated, leading to facilitation in performance. Previous studies have observed that the repetition of features shared among different stimuli can retrieve other features from episodic representation, leading to a greater CSE compared to when there was no repetition of the stimulus (Kreutzfeldt et al., 2016; Yang et al., 2017- Exp1A, 3A; Grant et al., 2020; Grant and Weissman, 2023, Kelber et al., 2023; Schiltenwolf et al., 2024; Dignath et al., 2021; Spapè and Hommel, 2008; Dignath and Kiesel, 2021; Dignath et al., 2019). De Cesarei et al. (2023) found that the repetition (vs. alternation) of stimuli (natural scenes) led to larger CSE. Their paradigm could not isolate the impact of these features from the repetition of stimulus categories. To address this, novel and frequently repeated images were presented in different conditions during a Picture Word Interference task, aiming to separate the effects of image repetition (i.e., perceptual/sensory features) from those of response repetition, which was tied to the superordinate category. Our results showed no significant effect of perceptual/sensory features repetition, indicating that only the superordinate category contributes to episodic representation rather than sensory/perceptual/sensory features repetition.

In terms of the electrocortical correlates of cognitive control, we also measured the electrocortical responses – the aperiodic exponent – in a second experiment, as it could be considered an electrophysiological index of cognitive control (Pi et al., 2023; Jia et al., 2024; Lu et al., 2024; Zhang et al., 2024). Research shows that conflict conditions are associated with a higher aperiodic exponent compared to non-conflict conditions (Jia et al., 2024; Zhang et al., 2024). Jia et al. (2024) found that higher aperiodic exponent during incongruent trials did not improve current performance, but performance in subsequent trials. For this reason, we investigated whether the modulation of aperiodic oscillations persists after the conflict event and whether it is driven solely by the conflict condition or also by the binding and retrieval processes within episodic representation, as observed in previous behavioral studies (Frings et al., 2020; Kreutzfeldt et al., 2016; Yang et al., 2017- Exp1A, 3A; Grant et al., 2020; Grant and Weissman, 2023, Kelber et al., 2023; Schiltenwolf et al., 2024; Dignath et al., 2021; Spapè and Hommel, 2008; Dignath and Kiesel, 2021; Dignath et al., 2019). In the EEG experiment, the behavioral results mirrored those of the earlier study: cognitive control – assessed through CSE – was influenced by the repetition of responses, indicating the involvement of superordinate category features in episodic representations. Additionally, the aperiodic exponent was higher during incongruent trials compared to congruent trials, suggesting cognitive control activation during conflict (Zhang et al., 2023; Jia et al., 2024). The effect was only seen when previous conflict was repeated, pointing to a binding-retrieval process (Frings et al., 2020). Our findings suggest that cognitive control can also be modulated by episodic representation, particularly by the repetition of the superordinate category.

The conflict can also be involved in dishonest responses, which we focused on in the last chapter beginning with the “intention effect”: a phenomenon observed in the dishonest task in which slower response times are associated with dishonest behavior compared to honest responses (Foerster et al., 2017, 2018). This slowdown in responses could be due to the monitoring process activated by the conflict of the dishonest response (Foerster et al., 2017, 2018, 2023), which can persist beyond the response itself (Foerster, 2023). Since previous research (Veira and Lane, 2013; Otgaar et al., 2014, 2016) found that conflict due to lies affects memory, we studied whether this conflict only influences immediate responses or also impacts memory after a few days. To this end, we designed a study involving two experimental sessions spaced one week apart, allowing us to assess whether the cognitive conflict generated by lying extends beyond the present moment and affects participants' memory over time. In a Reaction Time Concealed Information Test (RT-CIT) paradigm, participants categorized items from two previously shown videos, as well as new items, into “old” or “new.” For the honest and new conditions, participants responded truthfully, while for the theft conditions, they provided dishonest responses. After a week, participants were shown the same images, along with new ones, and were again asked to categorize them as either "novel" or "old," to assess the impact of dishonest responses on memory. The findings revealed an intention effect, with slower response times in the dishonest condition compared to the honest one, consistent with prior research (Geven et al., 2021; Noordraven and Verschuere, 2013; Suchotzki et al., 2017; klein Selle et al., 2023; Verschuere et al., 2010; Foerster et al.2017a, 2017b, 2018). However, unlike Foerster et al. (2023), we found faster responses when trials followed dishonest trials compared to honest ones. We suggest that in our study, repeating the previous intentional response may have facilitated performance in the next trials (Priming effect; Bargh, 2014; Hommel, 2004). Notably, trials involving dishonesty were associated with faster responses when they followed another dishonest trial, as opposed to when preceded by honest and new trials. The same effect was observed during the repetition of the other conditions, but a stronger modulation was noted for the dishonest condition. This effect may be due to the retrieval of the previous control state activated during the dishonest response.

Moreover, the interference effect from dishonest responses was diminished when these trials were preceded by dishonest conditions rather than by new ones. This sequential effect may suggest that cognitive control is activated during conflict conditions, resulting in improved performance in subsequent trials, as observed in the CSE phenomenon. Instead, this pattern was absent in Foerster et al. (2023), where the switch task paradigm precluded the repetition of the prior response. One interpretation of the overall different pattern between the present results and the results of Foerster et al. (2023) is that the different paradigms may have engaged distinct characteristics of cognitive control. The authors employed a paradigm that could trigger cognitive flexibility, the capacity to switch between different tasks or strategies based on changing demands. Conversely, our experimental design activated cognitive stability, which refers to the ability to maintain focus and persistently engage in a task over time (Egner, 2023), as participants in our study were required to consistently operate within a single, unchanging task set, which reinforced sustained attention and task adherence.

Lying-related conflict also affected memory for crime-related objects after one week: We observed reduced accuracy for dishonest items of the first session, compared to items encountered in honest conditions, like the study by Vieira and Lane (2013). The lower accuracy for items in the dishonest condition during the first session may be explained by a conflict between the initial inclination to give honest responses and the requirement to provide dishonest ones (Suchotzki et al., 2017; Verschuere et al., 2010; Foerster et al., 2023). This conflict could hinder the consolidation of memory (Bjork and Bjork, 1992), as the participant must suppress the honest response to generate a dishonest one. Additionally, errors stemming from the conflict in dishonest conditions may have disrupted memory consolidation, leading to poorer recall (Bridger and Mecklinger, 2014). Consistent with this, we found that participants who performed poorly in dishonest conditions during the first session were the same individuals who showed impaired memory for these items one week later.

Contrary to previous conflict conditions, interference from emotional stimuli did not activate cognitive control. The second chapter studied whether cognitive control is activated to counteract the attentional capture of emotional stimuli acting as distractors. Additionally, we studied whether the repetition of sensory/perceptual features of emotional pictures could modulate the emotional capture. Emotional stimuli capture attention due to their relevance to survival (Dolan, 2002). This phenomenon has been observed in different tasks where emotional stimuli interfered with task-related activities (Bradley et al., 1996, 1999; Calvo and Nummenmaa, 2007; Okon-Singer et al., 2007). Moreover, a stronger congruency sequence effect (CSE) triggered by emotional words in conflict tasks has been observed, indicating that arousal enhances cognitive control (Zeng et al., 2017). Is cognitive control activated to inhibit the attentional capture of distractors even in a task that does not generate conflict? We replicated the paradigm from Codispoti et al. (2016), where participants had to quickly categorize two digits by parity (same or different) while ignoring emotional or neutral picture distractors. Results showed slower response times when distractors were emotional pictures, indicating interference from emotional stimuli, consistent with previous findings (Bradley et al., 1996, 1999; Calvo and Nummenmaa, 2007; Okon-Singer et al., 2007). We did not observe cognitive control activation in response to arousal interference, as in previous studies (De Cesarei et al, 2023; Dignath et al., 2017; Brown et al., 2014). If cognitive control had been triggered, we would have expected improved performance in the subsequent trials, particularly a reduction in interference. An explanation for not observing this pattern could be that the Picture Word Interference task and the task related to lying in our paradigm can be considered conflict tasks at the response level (Becker et al., 2024). In these cases, providing the correct response required inhibiting an automatic one (i.e., reading the word in the PWI task and telling the truth in the lie task). In contrast, regarding emotions, inhibition of any response was unnecessary since the conflict arose from the distractors capturing attention.

The results of the study on attentional capture by emotional stimuli suggest that the perceptual set or the effect of serial dependence, manipulated here as the repetition/alternation of picture degradation, modulated the interference from emotional stimuli. In particular, we investigated whether repetition of degradation would have mitigated emotional interference; this was not observed, and rather emotional interference was larger when the degradedness level was repeated compared to when it changed across trials (Beligiannis et al., 2022; Codispoti et al., 2021; Storbeck et al., 2006; De Cesarei and Codispoti, 2011, 2013; Mastria et al., 2024). This could occur because repeated exposure to perceptual/sensory features can create a perceptual set – a tendency to focus on specific sensory information while filtering out others (Biggs et al., 2015; Schyns and Oliva, 1999). Repeated exposure resulted in quicker reactions to neutral distractions when the filtering condition remained consistent, whereas response times were slower when the filter changed. In contrast, emotional distractors did not show this pattern, indicating that their significance persistently draws attention regardless of repetition. The impact of prior conditions on current performance appears to align more with the perceptual set theory (Biggs et al., 2015) rather than the framework suggested by Frings et al. (2020). An alternative interpretation could suggest a serial dependence effect, in which the perception of the current stimulus is modulated by the previous ones, creating a temporal effect on visual perception (Fischer and Whitney, 2014). When perceptual features or conditions (in the present experiment, the perceptual filter) are repeated across stimuli, individuals may infer a statistical connection between successive, similar stimuli, leading earlier stimuli to shape later perceptual judgments (Feigin et al., 2021) and our experiment speed up the participant in their responses during the neutral distractors.

In summary, the present thesis observes a similar pattern of semantic and dishonest conflicts, but a different pattern for emotional interference. During the semantic conflict, we observed the activation of cognitive control, which was influenced not only by the conflict from the previous trial but also by the repetition of the trial, particularly by the superordinate categorical feature of the stimulus, which in this case was the repetition of the response. In contrast, the conflict arising from the attentional capture of emotional responses does not appear to activate cognitive control. Moreover, repeated exposure to the same perceptual/sensory features of emotional stimuli enhances their attentional capture, leading to poorer performance. Finally, the conflict arising from the tendency to respond truthfully when a dishonest response is required seems to activate cognitive control. Responses preceded by dishonest trials were associated with faster reaction times compared to trials preceded by other conditions, suggesting that the previous conflict led to faster responses in subsequent trials. Moreover, the dishonest interference decreased after dishonest conditions compared to trials after new conditions, suggesting a sequential effect. Hence, different paradigms can activate the same characteristic of cognitive control. Namely, both the conflict introduced by dishonest responses and semantic interference may engage cognitive stability, as the task rule remained invariant across trials. Cognitive stability is the capacity to maintain attention and uphold a consistent approach to a task despite potential distractions or competing information. This form of cognitive control supports sustained engagement with the same task demands, enhancing performance by focusing cognitive resources on task-related goals. Cognitive stability is crucial in contexts where maintaining a particular task set is beneficial, as it reduces susceptibility to irrelevant influences and promotes a steady response pattern over time. This is the opposite of cognitive flexibility, which refers to the ability to switch between different cognitive tasks or mental sets in response to changing demands, which is observed in the dishonest paradigm by Foerster et al. (2023). Moreover, the repetition of the previous conflict condition led to the reactivation of the previous control, resulting in better performance in the next trials (Egner, 2023; Frings et al., 2020). This reactivation results in a reduction in interference effect, i.e., more pronounced CSE compared to trials where no control state is reactivated (Frings et al., 2020; Egner, 2014). In semantic conflict we observed the reactivation of previous cognitive control during the repetition of the superordinate category only. In the dishonest conflict, the repetition of the previous conflict conditions led to faster responses and a reduction in interference from the dishonest conditions.

The research highlights the complexity of cognitive control processes and the importance of the context in which conflicts arise. This nuanced understanding of cognitive control can inform more effective strategies in clinical settings, particularly in managing various types of conflict and interference. For instance, Paap et al. (2020) emphasize that adopting a comprehensive paradigm for assessing cognitive control could have significant implications for the evaluation and diagnosis of cognitive disorders such as ADHD, dementia, and traumatic brain injuries. By refining assessment methods, clinicians can better identify specific deficits in cognitive control, leading to more tailored interventions and improved outcomes for individuals facing cognitive challenges.

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