Alma Mater Studiorum - Università di Bologna

DOTTORATO DI RICERCA IN

PSICOLOGIA

Ciclo 34

Settore Concorsuale: 11/E1 - PSICOLOGIA GENERALE, PSICOBIOLOGIA E PSICOMETRIA

Settore Scientifico Disciplinare: M-PSI/01 - PSICOLOGIA GENERALE

DISTRACTION BY TASK-IRRELEVANT STIMULI: THE EFFECTS OF ENDOGENOUS SPATIAL ATTENTION AND VISUAL WORKING MEMORY LOAD

Presentata da: Shari Cavicchi

Coordinatore Dottorato

Elisabetta Crocetti

Supervisore

Maurizio Codispoti

Co-supervisore

Andrea De Cesarei

Esame finale anno 2022

Abstract

Our visual system has evolved to rapidly detect and recognize significant objects. Attentional mechanisms play a critical role in cognition because they determine which events might be selected for further processing. Highly salient stimuli are treated by the attentional system as essentially relevant and generate a priority signal that, in the absence of specific task settings, will capture attention. Salience can be determined by either low-level physical properties, like sudden changes in the environment or stimuli that are different from the surrounding background, but also by semantic properties, like the affective value of natural scenes. However, when significant stimuli are irrelevant for a task at hand, attention might be involuntarily diverted towards their location, and performance might be disrupted. To achieve goal-driven behavior, we need to ignore them and to avoid being distracted. It is generally agreed that top-down factors can help us to filter out distractors. A fundamental question is how and at which stage of processing the rejection of the attentional selection of salient distractors is achieved. Two circumstances under which the allocation of attention to distractors is supposed to be prevented are represented by the case in which distractors occur at an unattended location (as determined by the deployment of endogenous spatial attention) and when the amount of visual working memory resources is reduced by an ongoing task. The present thesis is focused on the impact of these factors on three powerful sources of distraction, namely auditory and visual onsets (Experiments 1 and 2, respectively) and pleasant scenes (Experiment 3). In the first two studies we recorded neural correlates of distractor processing, whereas in the last study we used interference effects on behavior to index distraction. Recent event-related potential (ERP) studies have shown that lateralized auditory and visual sudden onsets activate the visual cortex contralateral to stimulus' location, transiently boosting the processing of co-localized visual targets. The Auditory and Visual Contralateral Occipital Positivity (ACOP and VCOP) were interpreted as markers of this attentional biasing mechanism, that is

inherently cross-modal. The distractor-elicited visual cortex activation was initially proposed to reflect an automatic process related to exogenous orienting. However, a few recent studies have suggested that task demands might modulate it. The behavioral interference (i.e., a slowing down of response times) caused by irrelevant emotional stimuli on a simultaneous task is considered an index of preferential allocation of attention to the distractor, in spite of task-relevant stimuli. The observed results challenge the hypothesis that exogenous attention to auditory and visual distractor onsets is automatic. Endogenous spatial attention played a role in reducing the ACOP amplitude and in eliminating the VCOP modulation. Visual working memory load did not affect auditory distractor processing, but eliminated the activation of the visual cortex when elicited by a visual sudden onset (even though other factors may have mediated this effect, as will be discussed). Conversely, interference by affective stimuli persisted even when scenes occurred always at unattended locations and when visual working memory was loaded. Altogether these findings indicate that the ability to detect the location of salient task-irrelevant sounds and identify the content of significant external events, as their affective significance, is preserved even when the amount of visual working memory resources is reduced by an ongoing task and when endogenous spatial attention is elsewhere directed. Moreover, the present results challenge the hypothesis that the visual-cortical enhancement elicited by sudden distractors is entirely automatic, as it might be affected by task demands.

CONTENTS

INTRODUCTION

Imagine you are working from home, and your phone starts ringing, your neighbor’s baby starts crying, and a pop-up message appears at the corner of your monitor. Sometimes you are so engaged in a task that you might fail to notice this background noise, but most of the times you will be distracted by such events. How can we ignore distractors?

Selective attention is the set of mechanisms that allow to select those stimuli that are most relevant in a given moment and filter out everything else. To adaptively interact with the outer world it is necessary to balance between concentration and responsiveness to external stimulations. Some classes of stimuli, such as abrupt onsets or emotional stimuli, can capture attention even if they are not essential for the achievement of our immediate goals. Intuitively, if salient objects automatically capture attention, then we would constantly be distracted and would not be able to achieve our goals.

The main aim of the present thesis was to test whether distractor processing is automatic or if it is modulated by task demands, and at which stage. A phenomenon is said to be fully automatic when it is unintentional, solely driven by a stimulus’ properties, and independent of the demands of the current task (Moors & De Houwer, 2006). So, it has not only to be elicited by items that do not match the attentional set of a participant, but it also must be unaffected by task demands. In the present work we sought to implement a paradigm in which the distractor could distract regardless of the observer’s task set (i.e., saliency-based guidance), as designing experiments that manipulate targets and distractors independently from each other is fundamental in order to properly assess distraction (Wöstmann et al., 2021).

Across three experiments we presented task-irrelevant auditory (Experiment 1) and visual (Experiment 2) onsets or emotional scenes (Experiment 3) during a visual working memory task, and manipulated the level of load and the correspondence between the task-relevant location and the one of the distractor. We explored whether visual working memory load and endogenous spatial attention might determine the extent to which attentional resources are allocated to task-irrelevant events.

In this introduction, I will start by reviewing some of the evidence that indicate that attentional capture might be prevented under some circumstances, and some of the studies that demonstrated a role for endogenous spatial attention and visual working memory load in affecting distractor processing.

CHAPTER 1 – THE TOP-DOWN CONTROL OF ATTENTIONAL CAPTURE

1. THE EFFECTS OF ATTENTIONAL CAPTURE

At any given moment we receive an abundance of input that exceeds our processing limitations. Our system has developed specific mechanisms for the selection of relevant information, allowing for efficient behavior. Each stimulus has to pass a sequence of processing stages and the system must necessarily, at some point between sensory input and action, place a bottleneck that interrupts event processing. Selective attention has been suggested to be that bottleneck, guided either in a “bottom-up” (also called exogenous or stimulus-driven) or a ‘‘top-down’’ (also called endogenous or goal-driven; Kim & Cave, 1999; Itti and Koch, 2000; Theeuwes, 2018) way. Bottom-up control refers to conditions in which attention is captured by the properties of the stimulus. Bottom-up attention might be guided by the physical salience of a stimulus, like a sudden noise or a visual element that contrasts with the surrounding background, but also by the intrinsic motivational relevance of a stimulus, for example, its affective value. Top-down deployment of attention describes the case in which one’s goals determine which stimulus will be attended to, for example when the system has a template for what type of object to look for. Such a top–down mechanism allows for selection according to task relevance and is fundamental for goal-directed behavior. In contrast, the ability to rapidly detect salient or ecologically significant stimuli and adapt one's behavior accordingly is fundamental for survival, as salient signals might warn us about potential dangers or benefits in the environment. However, the processing of salient stimuli when they are task-irrelevant causes distraction and may have detrimental consequences in real-life situations (e.g., while driving or working).

Bottom-up attentional selection is driven solely by the attributes of a stimulus. Some of the features that confer a special status to stimuli are related to their physical salience, for example (a) sudden changes in luminance (i.e., abrupt onset; Jonides, 1981; Jonides & Yantis, 1988) or (b) elements that stand out from their environment (Theeuwes, 1992), and are assumed to capture attention in a bottom-up way. The effects of attentional capture have been widely studied by analyzing how goal-driven behavior is impacted by allocation of attention to salient stimuli when they are task-irrelevant. A phenomenon that is often observed when a salient stimulus is detected and captures our attention, is that of spatial attention being exogenously directed in its direction. This shift in spatial attention could result in either costs or benefits. For instance, the outcome of bottom-up control might be either:

(a) Distraction. This term will be used hereafter to describe the concept of perceptual distraction (i.e., excluding phenomena related to the allocation of attention to internal thoughts). Distraction happens when we attend to an external event that we do not need to pay attention to in order to complete goal-directed behavior, with the consequence of having ongoing mental processes transiently interrupted (Buetti & Lleras, 2016). We all experience it quite often in everyday life, for example when we are reading a book and the phone starts to ring, or when our attention is captured while driving by a flashing billboard on the roadside. In all these cases, our attention is grabbed by elements of the environment with the aim of giving them priority in the processing stream because of their ecological relevance (e.g., Theeuwes, 2018).

(b) Spatially-specific enhancement (exogenous cuing). When attention is directed toward the location of a salient stimulus, even if it is task-irrelevant, beneficial effects are usually observed when that location corresponds to that of a subsequent target (Folk & Remington, 1998). Indeed, around 100–200 ms after the onset of a distractor, a rapid and transient spatially-specific enhancement in the processing of targets can be observed. This effect is short-lived (e.g., Müller &

Rabbitt, 1989) and even changes to inhibitory effects at longer cue-target intervals (inhibition of return, IOR; e.g., Klein, 2000).

1.1. The Attentional Capture Debate: the Stimulus-Driven Selection Perspective

As previously introduced, elements that stand out from their environment are assumed to capture attention in a bottom-up way. The extent to which this class of stimuli capture attention in a purely bottom-up way has been a matter of controversy in the literature. Precisely, a question that dominated longstanding debates in the attentional literature was whether or not top-down mechanisms could override bottom-up capture. There is general agreement with the view that incoming (visual) information is first collected into a sensory register and then decomposed and relocated in feature maps that represent simple features, like color, edge orientation, or luminance. After a stage assigned to saliency computations, the feature maps finally converge into a single priority map (Luck, Gaspelin, Folk, Remington, & Theeuwes, 2021). According to current models of attentional selection, some classes of stimuli (e.g., abrupt onsets or color singletons) generate a priority signal that, in turn, exogenously drives attention to the location of the stimulus. Initially, it was proposed that attention can be controlled in a purely bottom-up way, regardless of top-down control mechanisms (stimulus-driven selection hypothesis; e.g., Theeuwes, 2010). More recent views, however, include a role for learning mechanisms in reactively and proactively affecting the priority map. Precisely, the priority of a specific location might be either increased or reduced by proactive and reactive processes (even though there are areas of disagreement among researchers).

Traditionally, the additional singleton paradigm was used to investigate attentional capture by color singletons (i.e., items of a unique color surrounded by homogeneously colored items; Theeuwes, 1992). In this paradigm, observers search for a target defined by its unique shape compared to surrounding items (e.g., a single diamond target surrounded by circle non-targets), and have to identify some property of a stimulus enclosed within the target (e.g., the orientation of a line). A salient color singleton (i.e., an item of a unique color surrounded by homogeneously colored items) is either present or absent, but is never the target. Reaction times (RTs) are usually delayed when a salient color singleton is present in the visual search as a distractor, compared to trials without a color singleton distractor (Theeuwes, 1992). The theory for stimulus-driven selection described these results in terms of reflexive allocation of attention to physically salient task-irrelevant objects, proposing that the pre-attentive processing is exclusively driven by the bottom–up properties of the input. For instance, the color distractor singleton is never the target, so, in principle, observers could just ignore it. Attention is initially allocated to events that are salient enough, irrespective of the current task set imposed by task instructions (e.g., Theeuwes, 2010). More recently, it has been posited that information processing can be influenced by inhibitory mechanisms that directly boost or suppress the priority at specific locations. Implicit learning of a specific location or feature being task-irrelevant might determine a very fast disengagement of spatial attention from the location of a given distractor (after a first obligatory shift of attention; reactive inhibition) that results in no observable interference effect (Theeuwes, 2010), but also a proactive suppression that is applied before the search display onset (Wang, van Driel, Ort, & Theeuwes, 2019; as shown using electrophysiological markers of distractor suppression; see section 1.3).

1.2. THE ATTENTIONAL CAPTURE DEBATE: THE CONTINGENT INVOLUNTARY ORIENTING PERSPECTIVE

A contrasting perspective that has dominated the attentional capture literature (Folk, Remington, & Johnston, 1992) argues that appropriate attentional control configurations modulate saliency-based processing. When the features of a target (i.e., the attentional control setting) are known in advance, they are processed with priority (the contingent involuntary orienting hypothesis; Folk et al., 1992). According to this account, not saliency signals, but elements matching the properties that are relevant to the attentional set capture attention obligatorily. When a feature-specific task set is active, salient visual objects in visual search contexts are selected only if they match a currently active setting for target features. This account is at odds with the stimulus-driven account of attention, that does not include a role for attentional set in the guidance of attention. Initial support for the contingent involuntary orienting hypothesis was provided by spatial cuing tasks (e.g., Folk et al., 1992), in which a cue display was quickly followed by a target that participants had to recognize, presented at one of four possible locations. The target could be a singleton color, surrounded by objects of other colors (color condition), or could be the only object in the display (onset condition). Before its appearance a color cue (a location was surrounded by red dots and the other three locations by white dots) or an onset cue (one location was surrounded by an onset of white dots whereas the others were empty) was presented. The location of the cue was not predictive of the target's location (the cue and target locations corresponded only in 25% of the trials, namely at chance level). Attentional capture was calculated by comparing responses to a target that was preceded by a salient stimulus occurring at the same location with a target preceded by a salient stimulus occurring at a different location. The presence of exogenous cuing effects was used as an index of attentional capture and was observed only when there was a match between the properties of task-irrelevant cues and target (e.g., onset-onset, but not onset-color). The conclusion was that visual input only captures attention if it is somehow important to the observer (Posner, 1980), and in the case of contingent capture importance is determined by attentional control settings. When no control settings are active, attentional capture by salient events can take place.

While there is general agreement regarding the penetrability of saliency-based processing to top-down mechanisms, a major issue still concerns the stage at which attentional capture can be prevented by top-down mechanisms. Both perspectives support the hypothesis that the allocation of attention to saliency-signals might be controlled by either proactive or reactive mechanisms, depending on the experimental context. These mechanisms might impact distractor processing either before (proactive) or after (reactive) an initial attentional shift toward a distractor's location. For example, task experience might encourage the use of proactive control strategies to tune target selection prior to display onset and optimize overall task performance. A fundamental methodological advance that allowed for a better understanding of the stage at which attentional capture can be prevented was represented by the integration of psychophysiological indexes to the study of distraction.

1.3. TASK DEMANDS COUNTERACTING ATTENTIONAL CAPTURE

A vast body of research has explored attentional capture, and its penetrability to top-down manipulations, by measuring the impact of distractors on behavior. However, when using behavior as an index of distraction, it is difficult to understand whether a given item has actually captured attention. For example, distraction can be inferred when RTs are slowed down by the presence of a task-irrelevant event. The absence of such an effect may indicate that the salient object did not capture attention, but also that attention was briefly allocated to the salient event but then rapidly disengaged from it. Support for task-set contingent capture was usually obtained in experiments that employ spatial cueing procedures (Luck et al., 2021), in which the salient stimulus occurs prior to the target display. In such a paradigm, attention has the time to be disengaged from the distractor and reoriented before the target appears, and this could abolish possible behavioral costs.

Critically, behavioral responses come at the end of a stream of processing stages. Together with behavioral effects, and even in their absence, distraction by a task-irrelevant event can be indexed by measures of electrocortical activity (i.e., event-related potentials, ERPs) that are elicited when the event is detected and exogenously drives attention. ERPs provide a continuous measure of processing characterized by high temporal resolution that allows us to understand the processing stage at which a distractor can be filtered out. Two indexes have been widely used to index the selective processing of an attended target (N2pc) and the active suppression of a distractor (distractor positivity, PD). The N2pc is a posterior enhanced negativity, observed on the electrodes contralateral to the position of an attended visual event and starts 200–300 ms after the onset of the triggering event (e.g., Eimer & Kiss, 2008; Hickey, McDonald, & Theeuwes, 2006; Mazza, Turatto, Umiltà, & Eimer, 2007). It was suggested that N2pc reflects the shift of attention toward the location occupied by a visual stimulus target. Differently, the PD is an enhanced positive potential observed contralateral to a singleton non-target 180–200 ms after stimulus onset. This component was associated with an inhibitory mechanism that is engaged before the orienting of attention toward a distractor's location. Indeed: (a) its amplitude correlates with participants' ability to respond to a target (larger PD amplitudes were associated with less singleton interference; Gaspar & McDonald, 2014); (b) the timing of the PD makes it very unlikely that attention was shifted to a distractor before the suppression began; (c) in a study recording both ERPs and eye movements, the PD component was elicited only in trials in which gaze was immediately directed toward the target, but not in trials in which gaze was initially captured by the singleton (Weaver, van Zoest, & Hickey, 2017).

These changes in electrocortical activity showed that some classes of stimuli (e.g., abrupt onsets, color singletons), in the absence of specific attentional control settings, generate an attend-to-me signal that captures attention. The capture of attention by salient singletons, however, was observed to be non-automatic (i.e., "[…] elicited identically under all possible task conditions and brain states"; Hillyard et al., 2016, p. 177), but influenced by the current task set. For instance, Eimer and Kiss (2008) explored the role of bottom-up salience and top-down task set in determining distraction by salient non-target singletons using the N2pc as a marker of attentional spatially-specific selection. They observed a significant N2pc in response to spatially uninformative color singleton cues that preceded visual search arrays. Even though this could suggest attentional selection of visual stimuli that were task-irrelevant, cue-elicited N2pc was observed only when the subsequent singleton targets were defined by the same dimension as the task-irrelevant event (i.e., when the task was to report the orientation of a uniquely-colored target bar and the distractor was a singleton color cue; but not when targets were abrupt onset items or size singletons). This finding suggested that attention was captured by color singletons only when the color dimension was currently task relevant. Similar findings were observed in RSVP (Leblanc, Prime, & Jolicoeur, 2008), simple pop-out visual search displays (Kiss, Jolicœur, Dell'Acqua, & Eimer, 2008), and other spatial cuing tasks (Eimer & Kiss, 2010), suggesting that distraction is small or absent for singleton stimuli that do not have task-relevant features and that perceptual salience is necessary but not sufficient to determine the probability that visual task-irrelevant singleton stimuli will capture attention. This is in contrast with the evidence supporting the stimulus-driven selection hypothesis, which argued that the initial orienting of attention is solely driven by physical salience.

Another claim against the automaticity of attentional capture has been provided by studies supporting the signal suppression account (e.g., Gaspelin & Luck, 2018). According to this account, attentional capture by color singletons can be proactively suppressed by top-down control mechanisms, even before an initial shift of visual attention is completed, as selection is guided by pre-attentive feature processing. Supporting evidence has been provided by studies using the PD component as an index of distractor suppression. For example, in one study participants reported whether a specific target letter (the target was defined by a specific shape, size, and color; e.g., a large green “A”) was present or absent within an array of several letters (Sawaki & Luck, 2010). A salient color singleton occurred as a distractor in some trials (e.g., a red “O”). When present, the singleton elicited a PD component, suggesting that it was suppressed. It is of note that the signal suppression account provides evidence that contrasts with the disengagement account, which claims that visual attention initially moves to the most salient item in a display, and only after an initial shift it is disengaged. The signal suppression account proposes, on the other hand, that the priority of items that contain a particular feature can be reduced by feature-based control mechanisms which are available after extended practice in a specific visual search task, and that work in parallel on the entire display, suppressing the priority signal generated by salient but task-irrelevant stimuli (Luck et al., 2021).

In conclusion, this brief (and not exhaustive) introduction to current models of attentional capture might indicate that the orienting of attention to salient but task-irrelevant stimuli is not entirely automatic, but rather affected by task demands (Luck et al., 2021). However, most of the reviewed evidence for the inhibition of attentional capture comes primarily from studies of color singletons. It is still possible that other classes of distractors are strong enough to overcome the top-down control mechanism described (i.e., proactive signal suppression). For example, it is still not clear whether or not proactive signal suppression might counteract capture by stimuli that are more powerful in capturing attention, such as abrupt onsets (Jonides & Yantis, 1988; Luck et al., 2021). The reviewed evidence came from studies exploring attentional capture in the visual domain. However, spatial attention was proposed to operate across a cross-modal map. Crucially, the hypothesis of an automatic capture by lateralized sudden visual or acoustic onsets has been challenged by the finding that endogenous shifts of spatial attention can counteract the effects of exogenous cuing.

1.4. Exogenous vs. Endogenous Spatial Attention: a Cross-Modal Perspective

As previously described, attention sometimes takes advantage of being captured by distractors, as is the case of exogenous cuing (Posner, 1980). It is commonly agreed that the mechanisms of spatial attention do not operate in a strict modality-specific vein, but that spatial attentional processing (at least between vision, audition, and touch) is mostly cross-modal. Cross-modal approaches to the top-down control of distractor processing are widespread in the attentional literature, as it has been suggested that sounds represent particularly powerful tools with which to study distraction. On the one hand, the acoustic system has been described as an early warning system, as hearing constantly monitors the environment and can detect stimuli from any direction (e.g., Henneman, 1952; Szychowska & Wiens, 2020). Indeed, sounds can be particularly effective cues as they allow one to direct attention toward significant events that are not available to vision, because they originate from distal sites, for example (Spence & Driver, 1997). On the other hand, acoustic distraction is very common in daily life (e.g., people in the background talking on their phones while we are working in an open office). Sudden sounds are salient enough to be prioritized and capture attention in a bottom-up way, as described by many lines of research. In addition, their processing can elicit either overt or covert responses. Imagine reading a book and an alarm starts ringing suddenly outside your window. You will probably orient your attention in the direction of the window. The overt orienting reflex involves the coordinated reaction of eyes, head, and body in the direction of the salient event, with the aim of enhancing the processing of it (Sokolov, 1963; Thompson & Masterton, 1978). Besides this overt response, covert orienting does not involve overt receptor shifts but may also be triggered (Spence & Driver, 1997).

Spence and Driver (1994) used a spatial cuing context to investigate whether having one side or another cued by lateralized sounds could enhance participants' ability to discriminate the elevation of a subsequent target sound ("orthogonal-cuing" method; Spence & Driver, 1994). They observed a benefit in elevation judgments given by the correspondence of auditory target and cue locations, even though the cues were spatially uninformative (i.e., the position of the cue was randomly associated with the position of the following target). Similar results were replicated in cross-modal exogenous cuing contexts, to examine whether uninformative auditory cues may affect both auditory and visual target processing (Spence & Driver, 1997). Indeed, cross-modal cuing effects were observed, with faster and more accurate responses to visual targets that followed a task-irrelevant acoustic cue on the same rather than the opposite side. In the past few decades, researchers came to the conclusion that cross-modal effects of exogenous orienting could be observed on combinations of cues and targets presented in auditory, visual, and tactile modalities (Spence, 2010; Spence & McDonald, 2004). Auditory distractors, in particular, were observed to influence vision in a variety of contexts, such as increasing the perceptual sensitivity in detecting degraded co-located visual stimuli (McDonald, Teder-Sälejärvi, & Hillyard, 2000), in the context of time-order judgments for simultaneous targets occurring at the same or opposite locations (TOJ; McDonald, Teder-Sälejärvi, Di Russo, & Hillyard, 2005), and in the illusory line motion effect, in which a horizontal line that is briefly flashed is usually perceived to start from the location cued by a previous task-irrelevant sound (McDonald, Whitman, Störmer, & Hillyard, 2013).

Prior work was aimed at exploring the conditions under which the system is more attracted by potential sources of sensory distraction, and the factors that could prevent exogenous orienting. First evidence suggested that bottom-up capture could not be prevented. For example, Jonides (1981) instructed observers to actively ignore a peripheral onset cue, but results showed that capture could not be prevented voluntarily. Later on, endogenous spatial attention was observed to affect exogenous shifts of attention in both uni- and cross-modal contexts (Chica, Bartolomeo, & Lupiañez, 2013). Theeuwes (1991) observed that when visual spatial attention was endogenously shifted to a location in space by a fully predictive cue, bottom-up capture by visual onsets was eliminated. Precisely, when observers were asked to direct their attention towards a location in space pointed-at by a central arrow, abrupt onsets occurring elsewhere had no impact on performance. Santangelo and colleagues (2007) observed that unimodal and cross-modal auditory and visual exogenous spatial cuing effects could be abolished when endogenous attention was elsewhere engaged. They used a dual-task paradigm, in which the first was the orthogonal-cuing task (Spence & Driver, 1994). For the second task participants had to monitor a centrally-presented rapid serial visual presentation (RSVP) stream or a rapid serial auditory presentation (RSAP) stream for occasionally presented targets; the authors used a non-lateralized task to engage endogenous attention at the center of the display. Performance in this dual-task context was compared to performance in a single-task condition, in which participants were only required to perform the cuing task (cuing task alone vs. RSVP stream visible but in passive viewing). Spatial cuing effects were eliminated when participants simultaneously had to monitor the central stream for a target, in contrast with the initial claim for automaticity of exogenous orienting.

1.5. ATTENTIONAL CAPTURE BY EMOTIONAL DISTRACTORS

Even though we referred to bottom–up selection driven by low level features (e.g., color singletons or abrupt onsets), other stimuli attributes may capture attention, such as the emotional content of stimuli (e.g., romantic scenes; Bradley, 2009). Indeed, the recognition of natural scenes may be achieved very rapidly (De Cesarei, Cavicchi, Micucci, & Codispoti, 2019). Based on an initial extraction of basic visual features, the system normally analyzes the incoming information and determines whether or not it is relevant and should receive further processing (De Cesarei, Loftus, Mastria, & Codispoti, 2017). Relevance may be determined by the task-set, if the input is the target for the ongoing task, by the physical salience, as in the case of sudden visual or acoustic changes in the environment, but also by a stimulus' implicit value, like emotional scenes, which have gained a special status through evolution (e.g., Pessoa, 2008).

Emotional processing evolved to evaluate important elements of the environment (e.g., potential mates or dangers) to the final aim of responding adaptively to them (i.e., via approach vs. avoidance behaviors, respectively). It was proposed, accordingly, that emotion is organized around two cortico-limbic motivational systems, one defensive and one appetitive (Bradley, 2009). The engagement of these systems determines whether or not an event will be judged as “significant”. For instance, when an emotional scene is recognized, it is evaluated across two dimensions (dimensional approach; Bradley, 2009). The first is affective valence, which determines the direction of the motivational system that is engaged (defensive or appetitive, for unpleasant and pleasant contents, respectively). The second is arousal, which determines the intensity of activation (e.g., De Cesarei & Codispoti, 2008). Valence and arousal are important in determining how emotional events will be evaluated in the affective space, and subjective ratings on these dimensions covary systematically with the psychophysiological responses associated with motivational system engagement (Bradley, 2009; De Cesarei & Codispoti, 2008). When activation in either system is minimal, rated arousal is low and stimuli are usually considered as neutral (e.g., a picture of a person reading a book). Arousal increases when defensive or appetitive systems are more engaged, so when the event is either unpleasant (e.g., a mutilated body) or pleasant (e.g., an erotic scene), respectively.

In addition to subjective responses, the activation of motivational systems elicits a series of psychophysiological reactions that include autonomic responses indexed by changes in heart rate, skin conductance, and muscular activity (e.g., startle reflex; Bradley, 2009), and changes in cortical activity. Specifically, the late positive potential (LPP) is a sustained positive deflection elicited on the parietal cortex approximately 300 ms after stimulus onset, whose amplitude is modulated by the affective meaning of visual events. Aversive and appetitive pictures elicit a more pronounced LPP compared to neutral ones, and this affective modulation has been suggested to reflect the mandatory evaluation of an event and the activation of motivational systems that, in turn, engage attentional resources (e.g., Codispoti, Micucci, & De Cesarei, 2021; Micucci, Ferrari, De Cesarei, & Codispoti, 2020).

Attentional resources were observed to be allocated to emotional scenes even when attending to them was counterproductive for performing an ongoing task. When participants are actively engaged in an unrelated task, the amount of attentional resources that can be committed to the evaluation of affective stimuli is limited. However, emotional pictures still engage attentional resources, causing a poorer processing of the task, and disrupting performance. The emotional interference effect is measured by comparing performance in trials in which the task occurs together with a neutral vs. emotional stimulus. Importantly, Calvo and collaborators (Calvo, Gutiérrez-García & del Libano, 2015) observed (a) that emotional scenes (either pleasant or unpleasant) still caused an interference effect when the low-level perceptual properties between neutral and emotional pictures were controlled, excluding that the phenomenon was driven by mere perceptual factors; (b) that interference was still present when the emotional distractors were presented in peripheral vision. Precisely, they presented a scene (either emotional or neutral; or a meaningless scrambled picture balanced in low-level image properties) either peripherally (≥5°) or centrally for 150 ms. This was immediately followed by the task (a letter or digit discrimination task). They also assessed and balanced some low-level properties of the scenes, like their saliency, and the size of body and face areas of human figures in the scenes. Attentional capture was indexed by increased interference on performance in a concurrent task elicited by emotional compared to neutral scenes. The findings indicated that emotional scenes were recognized and captured attention even when appearing in the periphery, and when the impact of low-level differences across categories was minimized.

Besides natural scenes, attentional capture by emotional stimuli has been observed in paradigms using angry or happy facial expressions and affective words, even though the interference effects that are induced by these classes of stimuli are usually smaller compared to those caused by natural scenes. Importantly, independently of the valence, the level of arousal is critical in determining the extent to which emotional stimuli capture attention, with low-arousing emotional stimuli capturing attention similarly to neutral stimuli (Keil & Ihssen, 2004).

Crucially, as for low level features, the hypothesis of an obligatory attentional capture has been challenged by findings which show that there are factors that are able to reduce emotional distraction, suggesting that it is not entirely reflexive. It was recently argued that the impact of emotional task-irrelevant distractors is mediated by top-down factors. For example, the experience with emotional task-irrelevant scenes, induced via distractor frequency, is effective in attenuating the interference of novel emotional images (Micucci et al., 2020). Central to the scope of the present work, a factor that was observed to modulate attentional capture by emotional distractors is the type and level of processing load. The following sections are aimed at introducing the basic principles of the load theory.

1.6. The Theory of Load

A question that dominated longstanding debates in the attentional literature refers to where in the processing stream attention selects relevant stimuli. Two opposite accounts were proposed. The first hypothesized that objects are selected very early on, in the perceptual stages (Broadbent, 1958). The second assumed that selection occurs only at post-perceptual stages, after the semantic evaluation of stimuli (Deutsch & Deutsch, 1963). According to the filter model of Broadbent (Broadbent, 1958), the basic features (e.g., location, color, orientation, and spatial frequencies) of an event are first processed. Once their processing is completed, the information is used to decide whether an item is to be selected for further processing and awareness. These features are processed in parallel and pre-attentively, and only after this stage does selection occur. Unlike basic properties, semantic features (e.g., the identity of a word) are vulnerable to capacity limitations, so that only relevant selected stimuli are processed semantically. Initial evidence came from dichotic listening tasks, where separate auditory input was delivered in each ear. When participants were asked to recognize one of the two auditory streams, they could easily solve the task if the selection was based on low-level features, such as the spatial source of the stream. However, they were poorly aware of the content of the input coming from the unattended location, as only simple features could be recognized (Cherry, 1953; Moray, 1959).

Contrarily to Broadbent's predictions regarding selective filter theory, in some cases it was observed that the semantic content of acoustic unattended stimuli was able to influence behavior. These findings motivated the theorization of the late selection account, that holds that the semantic information is extracted from all stimuli (Deutsch & Deutsch, 1963). According to this account, the input's semantic analysis is not capacity limited and can proceed simultaneously across all elements. The role of attention is thought to be to select the items that should receive further processing resources and proceed in the processing stream to be encoded into working memory (Duncan, 1980). The locus of selection has often been investigated by analyzing the impact of unattended visual stimuli on behavioral performance. One of the most popular approaches was the flanker task proposed by Eriksen and Eriksen (1974). Within this paradigm, participants have to report the identity of a target letter that is briefly presented at an attended location, from a set of two possible target letters, each one associated with a specific response. The letter is flanked by other letters either mapped to the same response required by the target (congruent) or to the opposite response (incongruent). The typical finding is that behavioral responses are impaired when the target is flanked by incongruent stimuli rather than those that are congruent. The flanker effect (or congruency effect) provides evidence supporting the late selection approach, as it suggests that items outside the locus of attention impact the aim of responding to a target because their identity is recognized. Importantly, mixed results were observed regarding the impact of unattended information on perceptual processing, bringing forth evidence in favor of both early (e.g., Lachter, Forster, & Ruthruff, 2004; Sperling, 1960; Treisman & Riley, 1969) and late selection (e.g., Miller, 1987) approaches, and leading to the theorization of a new hybrid model, which holds that attention could select stimuli at different processing stages, depending on contextual factors: the model of load (Kahneman, 1984; Lavie, 1995; Lavie & Tsal, 1994).

Kahneman (1984) proposed that opposite findings were observed in literature because different types of tasks were used to explore the selectivity of attention. Evidence for the early selection hypothesis came from contexts in which participants were presented with a vast amount of information, had to attend to a specific item, and respond to it (filtering paradigms; e.g., Cherry, 1953; Sperling, 1960). Conversely, studies that supported late selection had observers presented with smaller display set-sizes requiring a simple detection or identification of elements that occurred alone or with a few other interfering elements (selective set paradigms; e.g., Posner, 1980; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). The authors suggested that these different paradigms encouraged the use of different attentional processes and strategies to complete goal-directed behavior, making it difficult to draw general conclusions about the locus of attention from the fusion of all the findings (Kahneman, 1984).

1.6.1. THE EFFECTS OF PERCEPTUAL LOAD ON RESPONSE COMPETITION TASKS

After an extensive review of the literature, the perceptual load imposed by the task was suggested to be a critical factor in determining the locus of attention (Lavie & Tsal, 1994). According to the load model, the locus of attentional selection can move as a function of the demands of the task at hand. Precisely, perceptual processing is limited in capacity, but proceeds obligatorily to analyze all information within its capacity limitation at a given time. The priority of allocation depends on which stimuli are classified as “task-relevant”. Irrelevant information is excluded from processing if all of the available resources are consumed by the prioritized task-relevant items. Thus, when the amount of information that has to be attended to in order to perform an ongoing task is large (high perceptual load), the limit is reached simply by processing task-relevant input and task-irrelevant information can be rejected at an early stage (e.g., Lavie, Beck, & Konstantinou, 2014). As a result, the impact of task-irrelevant items on performance is reduced or abolished. By contrast, when capacity is not fully exhausted by the processing of task-relevant objects (low perceptual load), leftover resources are spread among task-irrelevant to-be-ignored elements.

To test this model, paradigms that allow for task-related strategies to be manipulated during a single session are usually used. Most of perceptual load studies (e.g., Forster & Lavie, 2007; Lavie & De Fockert, 2003) manipulate the display set-size in variations of the flanker task, creating different levels of perceptual load (Eriksen and Eriksen, 1974). For example, observers can be asked to identify which of the target letters, X or N, is present in a display (Fig 1.1a). In the low-load condition, the target appears by itself or among non-letters, whereas in high-load trials, the target is presented among a set of neutral letters. The effect of reduced congruency effects (in terms of costs of incongruent non-targets relative to congruent or neutral ones) under high compared to low perceptual load has emerged across many studies (Forster & Lavie, 2007; Forster & Lavie, 2008; Lavie & Cox, 1997; Lavie & Tsal, 1994; Rees, Frith, & Lavie, 1997; Murphy, Groeger, & Greene, 2016). According to the model of load, this reduction in interference in high-load trials is due to the consumption of attentional resources by the processing of the task-relevant stimuli, resulting in no spare capacity left to process non-targets.

1.6.2. THE EFFECTS OF PERCEPTUAL LOAD ON ATTENTIONAL CAPTURE

In addition to measuring the effects of perceptual load on the extent to which stimuli mapped with an incongruent response interfere with task performance, Forster and Lavie (2008) developed a version of the task that could be used to explore the impact of perceptual load on the interference caused by events that are completely irrelevant for the task at hand (i.e., attentional capture by salient visual stimuli). In daily life, many sources of distraction reach our senses unexpectedly and from unattended locations, capturing our attention and interrupting our concentration. To measure attentional capture, salient visual figures (cartoon characters) that were entirely irrelevant for the task appeared close to it. The task-irrelevant stimuli interfered with the task only in the low perceptual load condition. High load eliminated attentional capture (Fig. 1.1b). Until that moment, the effects of perceptual load on attention were measured through the interference that a response conflict generated by a non-target associated with an incongruent response produced on task performance. In this study, however, distractor stimuli did not produce any response conflict. The findings indicated that interference by irrelevant distractors could be reduced by high perceptual load as could interference by incongruent stimuli in response competition tasks. The implications are fundamental for two reasons: (a) they shed light on a major issue in load literature, that is, the definition of distractibility and how to study it; (b) for the practical application of load theory, as it suggests that processing load may help one to ignore distractors regardless of their relevance for the task set.

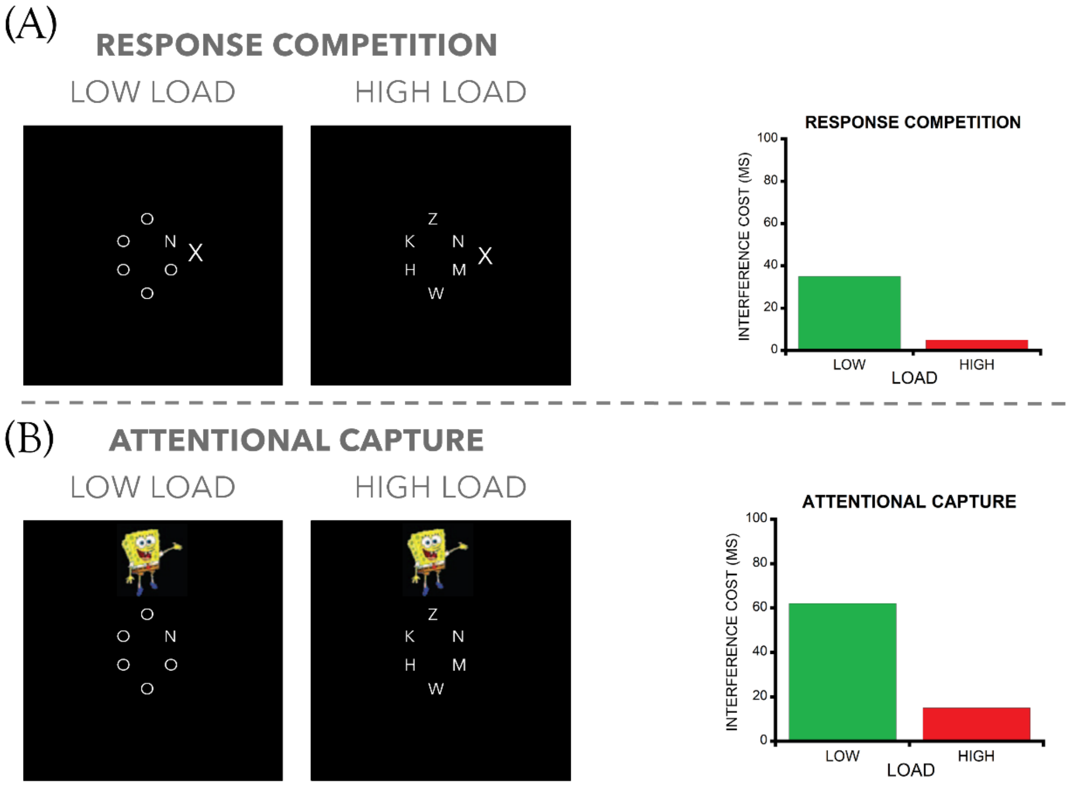

Fig. 1.1. Examples of paradigms used for studying perceptual load effects on interference and results. Panel (a) depicts an example of low and high load displays from Forster and Lavie (2007). The response competition paradigm was used to measure interference. The target letter appeared at a random position within the circle (X or N). To the left or right side the flanker letter appeared. The interference cost is measured as the difference between target responses in the presence of an incongruent minus congruent distractor. Interference in the response competition task was reduced under high perceptual load. Panel (b) depicts an example of low and high load displays from Forster and Lavie (2008). Irrelevant distractor images were used to measure perceptual load effects on attentional capture instead of response competition. Attentional capture by a task-irrelevant distractor cartoon was reduced by high perceptual load. Modified from Lavie (2010).

Even though there is broad evidence that perceptual load may affect attentional capture and congruency effects, results are mixed. On the one hand, upon investigation, the reduction of distractor interference under high perceptual load was not always observed (e.g., Benoni, Zivony, & Tsal, 2014; Marciano & Yeshurun, 2011; Theeuwes, Kramer, & Belopolsky, 2004), indicating that the distracting elements are not always unattended when perceptual resources are overloaded (Benoni, 2018). On the other hand, Lleras, Chu, and Buetti (2017) used the same paradigm used by Forster and Lavie (2008), in which cartoon characters are used as distractors. They showed that adding small variations to the original paradigm (e.g., varying the frequency of distractor-present trials), the opposite pattern of increased distraction with increasing perceptual load was observed. Hence, the predictions of the load theory are not always confirmed, suggesting that there could be several factors that moderate the effects of perceptual load. The load theory proposes that the efficiency with which observers reject distractor interference is also determined by executive control functions, usually related to working memory (WM; e.g., Lavie, 2010). WM is thought to actively maintain current processing priorities as imposed by the task set. This has motivated a large body of research focusing on the impact of WM load on distractor interference effects.

1.6.3. WORKING MEMORY LOAD

In conditions of low perceptual load, in which non-targets cannot be filtered out by early selection, it is not always the case that we are prone to distraction; there are other mechanisms that curb distraction. Imagine that you are walking to the supermarket while trying to remember the grocery list. The list could be longer or shorter. Would your distractibility be different across these two scenarios? Would your attention be similarly captured by a flashing advertisement billboard? In line with this reasoning, the addition of a concurrent WM load was used to create, within a single participant and a single session, two conditions characterized by a different number of available WM resources.

The general definition of WM, upon which almost all the models tend to agree, is that WM includes the processes that temporarily keep representations that are essential for ongoing cognitive tasks in an accessible state, and manipulate them (e.g., Baddeley, 1996; Cowan, 2017; Huynh Cong & Kerzel, 2021). It is supported by a broad network of brain areas (D'Esposito & Postle, 2015; Postle, 2006) and supports, in turn, a large range of functions, such as attentional filtering (Woodman, Luck, & Schall, 2007), the integration of information across saccades (Hollingworth, Richard, & Luck, 2008), language processing (Adams, Nguyen, & Cowan, 2018), and cognitive skills, such as fluid intelligence (Engle, 2002; Engle & Kane, 2004; Kyllonen & Stephens, 1990). Importantly, one of the properties that mostly defines WM is its limited capacity (Miller, 1956).

The load theory is based on the multicomponent model proposed by Baddeley and Hitch (1974), that proposes separate components for storage and processing. The passive storage systems are based on modality-specific codes, not necessarily determined by the modality of the input (e.g., words may be stored as phonological or visual codes, while colors may be stored based on their semantic codes). The phonological loop is a store for verbal information, and it is vulnerable to interference from tasks using verbal codes (e.g., repeating an irrelevant word aloud while retaining verbal sequences, as happens during articulatory suppression). The visuospatial store is aimed at briefly keeping visual and spatial information in memory (even though the two categories have often been suggested to be kept in separate stores; Logie & Pearson, 1997). Active modality-general (processing) processes aimed at preventing trace decay, were initially ascribed to the central executive, but replaced soon by a variety of separate executive functions, responsible for many cognitive operations such as updating, inhibition, and task-switching (Baddeley, 1996; Doherty et al., 2019). Within this perspective, WM is described as a combination of mental tools that support goal-driven behavior and a central executive that controls attention and moves information into specialized stores.

Hence, mechanisms of late selection might be supported by the executive subsystem of WM, that plays a central role in limiting distractibility (De Fockert, 2013; Lavie, 2010). Executive (or cognitive control) functions are thought to keep the attentional settings clearly defined, maintaining target and distractor-related information distinct and finally guiding attention in the selection of task-relevant information. Every time that we look for something, WM supports goal-directed behavior by actively maintaining current task-related priorities, namely representations of what information is set as "task-relevant" by task instructions (i.e., attentional control settings; Folk et al., 1992). Evidence supporting the role of executive functions in limiting distractibility came from individual difference studies, that observed a correlation between WM capacity and the degree of distractibility (Engle, 2002; Gaspar, Christie, Prime, Jolicoeur, & McDonald, 2016). In addition, it was also observed that loading executive functions (a condition often referred to as "cognitive load" or "WM load"; De Fockert, 2013; Murphy et al., 2016) often resulted in an increase in interference effects (in contrast with perceptual load, which reduces interference; De Fockert, 2013).

WM load is usually examined by presenting participants with something to remember (traditionally digits or letters), then, during memory maintenance, asking them to complete an attentional task (e.g., a visual search or a response competition task; De Fockert, Rees, Frith, & Lavie, 2001). In a pivotal study, Lavie and De Fockert (2005) compared singleton interference as observed in the additional singleton paradigm (Fig. 1.2) between a single-task condition and a dual-task condition in which, in addition to the search task, participants had to remember a set of six digits. The authors observed greater interference by the task-irrelevant singletons when participants had to remember a set of six digits (dual-task condition), compared to when the search task was presented alone (single-task condition), regardless of the nature of the WM test (probed letter vs. recall of digit order). This finding was replicated even when WM load was manipulated by varying the memory set size, excluding the possibility that the effect on interference was caused by a general increase in task demands due to task switching in the high load condition (but not in the low load one). Similar findings of increased distractor interference were observed when using congruency effects on behavior in variants of flanker or Stroop tasks as a measure of selective attention failure (e.g., Kim, Kim, & Chun, 2005; see De Fockert, 2013 for a review).

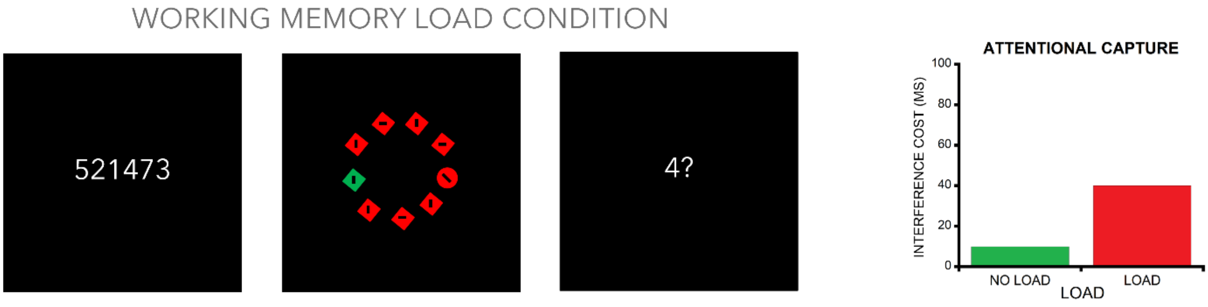

Fig. 1.2. Example of a trial in the dual-task condition of Experiment 1 in Lavie and De Fockert (2005). The additional singleton paradigm was used to measure interference. The target shape was a circle surrounded by eight diamond shapes. A singleton color nontarget was present in some trials. The interference effect was assessed by the extent to which target response times (RTs) were slower in the presence of the singleton. Attentional capture was increased when participant had to remember a set of digits compared to when they performed the search task alone.

Surprisingly, when De Fockert and Theeuwes (2012) used the same paradigm as Lavie and De Fockert (2005) no involvement was observed of WM load on the cost produced by the presence of an additional singleton. For instance, behavioral capture was unaffected by the degree of load on working memory. In contrast with the study by Lavie and De Fockert (2005), the singleton conditions (present vs. absent) varied across blocks instead of trial-by-trial. De Fockert (2013) proposed that the salience of singletons was reduced by their predictability and that this limited the penetrability of singleton interference to WM load manipulations. Opposite findings were described across a variety of studies, as for the effects of perceptual load. Some studies described enhanced interference effects (e.g., de Fockert et al., 2001; Lavie, Hirst, de Fockert, & Viding, 2004; Yi, Woodman, Widders, Marois, & Chun, 2004), other reduced effects (e.g., Gil-Gómez de Liaño, Umiltà, Stablum, Tebaldi, & Cantagallo, 2010; SanMiguel, Corral, & Escera, 2008; Spinks, Zhang, Fox, Gao, & Tan, 2004), and in other studies no impact of high WM load was found at all (e.g., Yao, Guo, Liu, Shen, & Gao, 2020). Several variables were proposed to account for the inconsistencies, such as the relationship between WM contents and stimuli used in the attentional task. Across a series of experiments Kim and colleagues (2005) observed that WM load effects on a Stroop task are conditioned to the overlap of WM contents with either the target or non-target elements. When the processing of the WM contents relied on the same resources as those employed by the non-target object, beneficial effects of concurrent WM load were observed, suggesting that WM load does not always impair performance. Conversely, interference increased when WM load consumed resources needed for target processing. This dissociation was deemed as evidence for the existence of separate subsystems of WM supporting the storage of specific types of information. This observation led to the fundamental suggestion that researchers should consider that dissociable effects could be observed depending on the type of information being processed, in terms of both to-be-remembered contents or distractors, as WM load may either impair or benefit performance in concurrent response competition tasks. It is of note that, in an attempt to replicate Kim et al.'s (2005) findings, Gil-Gómez de Liaño, Stablum and Umiltà (2016) conducted a series of experiments in which the paradigm was kept the same but the sample was increased. They did not replicate the findings, suggesting that other factors may mediate the effects of WM load.

In studies exploring the effects of WM load, executive cognitive control functions are typically manipulated via tasks that load verbal WM (e.g., Konstantinou, Beal, King, & Lavie, 2014). In this case, it is thus predicted that load on cognitive control WM functions results in increased distractor interference. Importantly, this is inconsistent with the most influential theories of WM, and also with the multicomponent model of WM (Oberauer, 2019). As an example, the capacity of central executive in WM literature is defined as the amount of information that can be processed efficiently in WM and tested via complex span tasks such as reading or operation span (RSPAN and OSPAN; e.g., Turner & Engle, 1989), that tax both storage and processing functions (e.g., solve a mathematical expression combined with word recall, with capacity inferred from the accuracy of serial recall). It is controversial to assume that the passive storage of verbal material alone (just like a typical manipulation in studies supporting load theory) is efficient in taxing the capacity of central executive.

In the past decade, researchers have begun to focus on the role of Visual Working Memory (VWM) load on selective attention, and distractor interference (e.g., Konstantinou & Lavie, 2013; Koshino & Olid, 2015; Roper & Vecera, 2014). The interest in VWM has grown exponentially because its inherent capacity limitations have been observed to correlate with overall cognitive skills and it can be measured using very simple tasks. What is more, it can be easily isolated at a neural level because its engagement elicits a well-known ERP component, namely the contralateral delay activity (CDA), that is a sustained ERP response during the delay period of VWM maintenance (Luck & Vogel, 2013). Manipulations of VWM were suggested to represent a peculiar case because of the involvement of the visual cortex in supporting the maintenance of visual objects (sensory-recruitment hypothesis; e.g., Harrison & Tong, 2009). Accordingly, recent studies indicated that high visual working memory (VWM) load leads to reduced distractor processing, in the same way as when perceptual resources are exhausted (Konstantinou et al., 2014; Roper & Vecera, 2014).

1.7. THE INDEXES OF VISUAL WORKING MEMORY

VWM capacity is usually taxed through variants of the change detection task (e.g., Lin & Luck, 2012; Luck & Vogel, 1997; Phillips, 1974). In this paradigm, a memory array consisting of a set of items (usually a set of colored squares) is briefly presented and followed by a short retention interval (usually at least 900 ms) in which no stimuli appear. This is finally followed by a probe array that participants must compare with the initial array to say whether they are identical or whether a change occurred (e.g., in the color of one of the squares). The set size can vary, with increasing task demands (i.e., VWM load), and the maximum of items that can be remembered is usually taken as an estimate of an individual's VWM capacity. There are two versions of the task: (a) single-probed recognition, in which the probe display consists of one unique item presented at a studied location; (b) whole-display recognition, in which the probe display consists of the full set of items (either with or without a change relative to the original studied set). The difference between the two versions is that in single-probed recognition, the participant is tested on a single item whereas in whole-display recognition, the participant does not know which item may change and, consequently, must evaluate the identity of each item. Usually better performance is observed in the single-probed version (Rouder, Morey, Morey, & Cowan, 2011; Wheeler & Treisman, 2002). In general, VWM capacity limit is three to four objects, at least when memory for unidimensional features (e.g., color) is tested. A basic model of VWM described it as a store that could contain a limited number of items (estimated via the K score); when the number of items from the sensory input exceeds this limit only a number of items up to K is stored, while the others are completely discarded (an alternative hypothesis conceptualizes VWM capacity as a more flexible resource, i.e., resource-based theories; Luck & Vogel, 2013). K score can be calculated via two formulae to estimate the averaged number of items that are stored in VWM as a function of the set size (i.e., N): (a) Cowan's K (N[hit rate – false alarms]; Cowan, 2001) for single-probed version; (b) Pashler's K (N[(hit rate – false alarms) / (1 –

false alarms)]; Pashler, 1988) for whole-display recognition. In addition to behavioral estimates, VMW storage is indexed in the ERPs by the Contralateral Delay Activity (CDA). This change in electrocortical activity is typically observed when bilateral presentation is used for the memory array, as this arrangement allows for the comparison of electrocortical waves elicited by items occurring at a cued (i.e., to-be-remembered) vs. a non-cued (i.e., to-be-ignored) location (Luria, Balaban, Awh, & Vogel, 2016). It is a slow negative wave starting from 300 ms after the onset of the memory array and lasting throughout the retention interval that is more pronounced in the occipital cortex contralateral to the cued hemifield compared to the ipsilateral one. Its amplitude increases along with the number of items to be remembered, until capacity limit is reached (three or four items; Vogel & Machizawa, 2004).

1.8. THE INFLUENCE OF VISUAL WORKING MEMORY ON ATTENTIONAL SELECTION

Following the finding that VWM correlates closely with some attentional functions (e.g., Cowan & Morey, 2006; Oberauer, 2019; Olivers, Peters, Houtkamp, & Roelfsema, 2011), the application of VWM manipulations has become popular. Indeed, attention and VWM are both aimed at supporting goal-driven processes by increasing the accessibility of task-relevant elements, and influence each other bidirectionally (Awh, Vogel, & Oh, 2006). Attention supports the activation, maintenance, and processing of VWM traces, optimizing the use of VWM capacity by prioritizing task-relevant information (Huynh Cong & Kerzel, 2021; Souza & Oberauer, 2016). In turn, VWM maintains an active representation of what is relevant for an ongoing task (i.e., an attentional template) and guides selective attention in its selection. Once an attentional template is activated, it interacts with selective attention, driving it to select objects with template-matching features, and optimizing the allocation of resources to task-relevant objects (e.g., Wolfe, 2020). Most of the evidence comes from experiments that combined VWM and search tasks. Indeed, it is usually observed that the act of remembering visual information affects performance in a visual search task presented during the memory maintenance period, with increased attention to those features in the environment that match those already stored in VWM. Intuitively, this is beneficial when VWM contents overlap with goals that are currently task-relevant. For example, if you are in a crowd looking for your friend, knowing that he is wearing a red jacket will make your search easier as your attention will be immediately captured by people wearing a red jacket, limiting interference to only these individuals among the whole crowd. Accordingly, in visual search studies it was observed that performance is enhanced if the search target matches the features of a stimulus stored in VWM (e.g., searching for a red target while remembering a red item for a subsequent delayed recognition task; Downing & Dodds, 2004; Olivers, Meijer, & Theeuwes, 2006). However, the search is impaired if the WM content matches search distractors (e.g., searching for a green target that is flanked by a red non-target while remembering a red item for a subsequent delayed recognition task; Dowd, Kiyonaga, Beck, & Egner, 2015). In other words, attentional templates "are thought to influence competition by means of working memory representations in visual cortex, which essentially preactivate the representations of goal-relevant stimuli and therefore confer an advantage to these representations" (Sawaki & Luck, 2011, p. 957). The implication for the hypothesis that attentional templates are kept in VWM is that an additional load on VWM should impact target selection processes. This hypothesis was tested by Berggren and Eimer (2018), who used the N2pc as a marker of template-guided target selection. They observed a delay of the target N2pc component when the search task was completed while maintaining a set of shapes in VWM, and particularly under a high VWM load. They suggested that this finding reflects the costs for the efficiency of template-guided attentional guidance resulting from the competition between these templates and other items kept in VWM.

In addition to promoting the selection of task-relevant items during visual search, VWM was also suggested to impact an individual's ability to filter out distractors. Accordingly, individual VWM capacity differences were proposed to be defined by the efficacy of the attentional filter, rather than by differences in capacity limitations. Low-capacity individuals basically fail to reject irrelevant information, that enters VWM and occupies resources that are necessary for the processing of task-relevant items. Differently, high-capacity individuals encode only relevant elements, using the limited store more efficiently. In an ERP study, Gaspar and colleagues (2016) analyzed the N2pc and the PD elicited during an additional singleton search task separately for individuals with low, medium, and high VWM capacities, as measured through a previous change detection task. They observed that the N2pc was unaffected by individuals' VWM capacity, but the timing and amplitude of the PD differed as a function of VWM capacity. Rather than a distractor singleton-elicited contralateral positive potential (i.e., PD), low-capacity participants' waves were characterized by a negative contralateral potential that is typical of attentional target selection (i.e., N2pc; Eimer & Kiss, 2008), suggesting that low-capacity individuals failed to reject capture by singleton non-targets. Together, these findings demonstrate the bidirectional interactions between attention and VWM storage, motivating the exploration of the effects of VWM load on attentional processes related to interference in response competition tasks.

1.8.1. VISUAL WORKING MEMORY LOAD AND THE SENSORY RECRUITMENT HYPOTHESIS

The load on VWM resources might be easily increased within a single experimental session by increasing the set size of the display. A great body of research used this set size manipulation to increase demands on VWM. In a pivotal study the congruency effect observed in a flanker task was compared in a condition in which the flanker task was performed while keeping visual vs. verbal information in WM. In Experiment 1 of Konstantinou et al. (2014), participants performed a change detection task, increasing the set size of the memory array in the high compared to the low load conditions (four vs. one, respectively). During the retention interval or the encoding phase (in two separate experiments), a flanker task was presented, requiring observers to recognize the identity of a target letter in the presence of a congruent or incongruent flanker (Fig. 1.3). The authors found effects similar to the ones produced by perceptual load, namely a reduced congruency effect in the flanker task under high VWM load. In addition, participants with lower VWM capacity were more prone to interference. In a second set of experiments they compared the magnitude of congruency effects as a function of verbal vs. visual WM load. In Experiment 2a the items in the memory array were letters that participants had to rehearse verbally. In Experiment 2b, participants had to remember meaningless symbols; it was assumed that this would tax each individual’s visual representation capacity. In the verbal WM task, the congruency effect increased under higher compared to lower WM load. Conversely, the effect of reduced interference under high VWM load was replicated in Experiment 2b. The authors proposed that active rehearsal of verbal information depends on executive resources, a position that, as previously noted, is not consistent with the most influential models of WM (e.g., Oberauer, 2019). The source of the VWM load modulation was identified by Konstantinou et al. (2014) in the early rejection of non-target letters (perceptual load hypothesis of VWM load effects), consistently with the hypothesis that VWM representations and online perceptual processing share the same resources (e.g., Pasternak & Greenlee, 2005). Indeed, it was suggested that early visual sensory regions support online perception of incoming visual information, as well as maintenance in VWM (sensory recruitment theory; D’Esposito & Postle, 2015; Pasternak & Greenlee, 2005; Postle, 2006; Serences, Ester, Vogel, & Awh, 2009). Supporting evidence came from:

(a) The description of competition between VWM and perceptual representations. If the same sensory representations support storage and perception, then there should be increased competition when there is greater overlap between the features of the contents stored in VWM and the incoming information. This hypothesis was confirmed in VWM recognition tasks using both simple features (Magnussen & Greenlee, 1992) and complex visual objects (e.g., pictures of faces;

Yoon, Curtis, & D'Esposito, 2006) as targets. A greater interference was often observed when distractors belonging to the same category as that of the target were presented during the delay interval, compared to a condition in which distractors from different categories were shown.

(b) Findings from functional magnetic resonance imaging (fMRI) studies showing that activity in the same visuo-cortical regions supports both VWM and the perception of incoming stimuli (i.e., sensory-specific representations are stored in early visuo-cortical areas; but see, Xu, 2017).

1.8.2. ALTERNATIVE HYPOTHESES

The perceptual load hypothesis of VWM load effects was supported by findings of reduced detection sensitivity for a contrast increment under high VWM load (Konstantinou & Lavie, 2013), that indicate competition between VWM and perceptual representations. However, other studies reported none or the opposite findings on response competition tasks (Guo et al., 2019; Lee & Yi, 2018; Yao et al., 2020; Zhang & Luck, 2015). Several alternative hypotheses were proposed to account for the inconsistencies. In addition to the perceptual load explanation for the VWM load effects: (a) a domain-specific hypothesis (Lin & Yeh, 2014), suggesting that it is only when the representations in WM are in the same domain as the attentional task that WM load modulates interference by means of a central executive load (e.g., remembering digits modulated the flanker effect when it included letters but not when the stimuli were shapes); (b) a resolution hypothesis, proposing that VWM includes functions assigned to either capacity or resolution (Zhang & Luck, 2008, 2015). A load on resolution is formed by increased demands for the precision of representations (i.e., memorizing two low- vs. high-resolution colors), and it taxes perceptual processing resources. Accordingly, just like perceptual load, distractor interference is reduced under high resolution load. VWM tasks emphasizing capacity (i.e., increasing the number of to-be-remembered colors, as in the most popular VWM load studies; e.g., Konstantinou et al., 2014) overload executive functions, leading to increased distractor interference.; (c) the attentional zoom size hypothesis (Lee & Jeong, 2020), that is based on the attentional zoom lens model (Eriksen & St. James, 1986), assumes that attention is spread within the area of the attentional focus. As processing resources are limited, the more restricted the area is, the more resources will be gathered in it. When the area is larger, the resources will be more scattered, but more items will fall into it. In typical VWM displays, the size of attentional zoom increases from high to low load conditions, so more distractor interference under high VWM load could be predicted, since a greater number of distractors are included within the attentional area. Indeed, increasing the size of attentional zoom would itself lead to greater distractor interference, but most of the prior studies did not dissociate the size of attentional focus and VWM load effects. So, the previous evidence for VWM load effects could be caused by differences in the size of attentional zoom instead of load per se (Fig. 1.3).

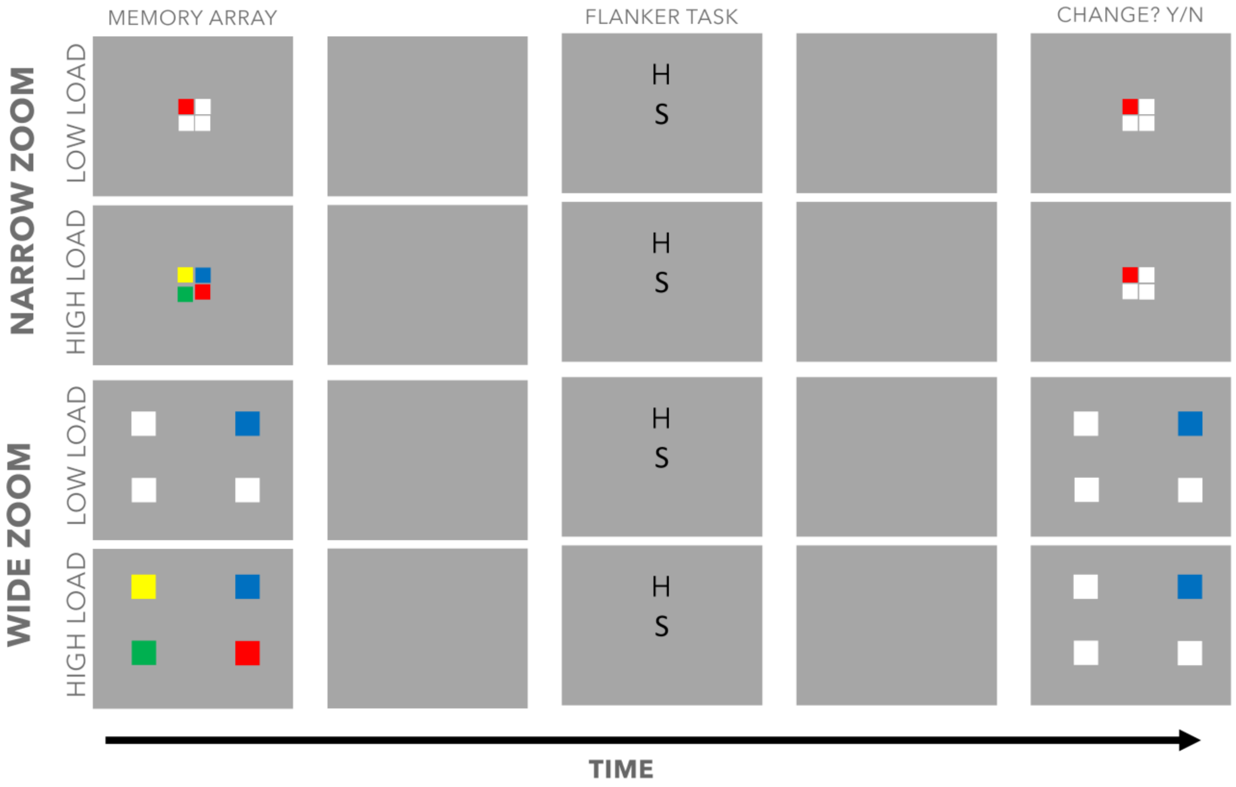

Fig. 1.3. Procedure and conditions used in Experiment 3 of Lee and Jeong (2020), in which both the size of attentional zoom and the visual working memory load were manipulated. Modified from Lee and Jeong (2020).

Whereas (a) and (b) tend to contradict the existing empirical evidence, (c) provides a framework that could partially reconcile existing mixed findings. For example:

(a) Lin and Yeh (2014) used a domain-specific approach, arguing that the failure to observe VWM load effects on interference effects may be caused by the lack of content overlap between the two tested tasks. However, Yao et al. (2020) failed to observe VWM load effects on interference even when using a color flanker task rather than a typical letter flanker task (i.e., participants had to respond to the color of a target shape, black or white).

(b) Zhang and Luck (2015) proposed that only when resolution is taxed (i.e., memorizing two low- or high-resolution colors) is a type of perceptual load induced. However, the effects observed in Konstantinou et al. (2014) were induced by increasing the number of to-be-remembered colors (loading VWM capacity). Other moderating factors may impact the direction of VWM load effects. As an example, the use of different strategies could be encouraged across different manipulations. In Konstantinou et al. (2014) and in the capacity load task of Zhang and Luck (2015) the items could be easily verbally coded during memorization, but this was difficult in the resolution condition.

(c) Lee and Jeong (2020) proposed that the size of the attentional zoom may have influenced distractor interference in prior studies, as it was mostly uncontrolled. They dissociated the effects of the attentional zoom size and VWM load, by adding a low load/wide zoom condition (since wide zoom is typical of high load), and a high load/narrow zoom (size typical of low load) to the paradigm used by Zhang and Luck (2015). In the narrow zoom conditions, the size of the squares was smaller to reduce the display size. In the low load conditions, three empty placeholders were added at the locations of the VWM high load array (Fig. 1.3). When the conditions used in Zhang and Luck (2015) were used (high load/wide zoom condition vs. low load/narrow zoom), the finding of increased interference in high compared to low VWM load was replicated. However, VWM load did not influence the amount of congruency effect when the size of attentional zoom was kept constant. When splitting results by narrow vs. wide zoom, interference was similar in high vs. low load conditions within each attentional zoom size. These findings support the hypothesis that the attentional window size moderates the effects of VWM load on flanker congruency effects.

1.9. INTEGRATION AND OUTSTANDING QUESTIONS

Physically salient stimuli are currently thought to generate a priority signal that, in the absence of specific attentional control settings, will result in attentional capture. It was observed that attentional capture is not immune to top-down penetrations. For example, specific attentional configurations can prevent color singletons from capturing attention. Sudden acoustic and visual changes in the environment are particularly powerful in capturing attention (Jonides & Yantis, 1988; Luck et al., 2021). A phenomenon that is usually observed when attention is shifted towards the location of a distractor is a rapid and transient spatially-specific enhancement for the processing of a co-localized event (i.e., exogenous cuing effect). Numerous studies examined both exogenous and endogenous spatial attention in multisensory contexts, and provided strong evidence for cross-modal spatial attention. Converging evidence supports the hypothesis that the effects of exogenous cuing on behavior might be reduced when attention is endogenously directed elsewhere. However, it is not clear the processing stage at which this modulation occurs.

Interestingly, recent ERP studies indicated that acoustic and visual spatial attention might converge on a map that is common to both modalities and that is supported by the visual cortex. For instance, changes in electrocortical activity have been observed to parallel the exogenous cuing effects elicited by both acoustic and visual distractors, namely the Auditory Contralateral Occipital Positivity (ACOP) and the Visual Contralateral Occipital Positivity (VCOP; Störmer, McDonald, & Hillyard, 2019). It is suggested that these changes in neural activity reflect a similar attentional biasing mechanism that is characterized by a transient visual-cortical enhancement induced in the opposite hemisphere to the location of a task-irrelevant stimulus. An outstanding question refers to whether or not the ACOP and VCOP reflect an automatic process. Two recent studies challenged the hypothesis that visual-cortical enhancement is automatic (as indexed only by the ACOP), indicating that it may be sensitive to task demands (Matusz, Retsa, & Murray, 2016; Retsa, Matusz, Schnupp, & Murray, 2020).

Another factor that was proposed to affect distractibility is VWM load. However, most of the evidence comes from studies measuring distraction using manipulations of the flanker task (i.e., a response competition paradigm). Methodologically, interference in response competition is studied in contexts involving manipulations of task-relevance of the distractors relative to task instructions (Lleras, Buetti, & Mordkoff, 2013). Indeed, to induce behavioral effects, the distractor must be designed to cause interference with the act of responding to a target. The same stimuli (i.e., a letter) would not impact behavior if they were not included in the task set. In typical flanker tasks, interference with the task is produced by items whose attributes are selected by the experimenter precisely to impact performance, inducing erroneous responses if attended to. The basic principle standing behind the flanker effect is that observers activate stimulus–response associations for each of the possible targets, and thus if the distractor is chosen from the set of targets, it will necessarily activate its specific association. If that association is incongruent with that of the target for the given trial, it will compete with the information coming from the current target. Although it is still true that non-targets carry no information concerning the correct response to a given trial, they are just "irrelevant" with regard to the response, not to the task. As argued by Lleras and colleagues (2013), the dominant definition of distractors as task-irrelevant instead of response-uninformative, probably comes from the traditional use of the term "task-irrelevant", that was initially ascribed to something that did not help participants to properly respond to a target. They labelled these types of stimuli "foils", because they can elicit an incorrect response (Buetti & Lleras, 2016). VWM load theory literature consists of studies on the effects of foils on performance, that is something different from distractibility. For instance, the orienting of attention driven by task-relevance reflects a different mechanism compared to attentional capture. For example, response competition paradigms require active attentional control mechanisms to reject automatic responses elicited by foils. Attentional control is thought to reflect the ability to regulate information processing during goal-directed behavior (e.g., inhibiting responses to interfering information) and was traditionally linked to working memory (Von Bastian et al., 2020). The effects of VWM load on the exogenous orienting (i.e., attentional capture) toward task-irrelevant objects that do not elicit response conflicts are thus still mostly unexplored. Is attentional capture by salient elements falling outside the attentional set of the observer susceptible to VWM load? In the following sections I will introduce the indexes that we used to test the penetrability to top-down factors of distractor processing.

1.9.1. THE AUDITORY CONTRALATERAL OCCIPITAL POSITIVITY (ACOP)

A recent line of research has been focusing on the neural correlates of spatial attentional processing, and observed that lateralized task-irrelevant sounds activate the visual cortices contralateral to sound location. The rationale that initially motivated this line of studies was that, if a lateralized sound could modulate the processing of a subsequent visual target (see section 1.4), then some anticipatory biasing activity may be observed on the visual cortex. In a series of studies, McDonald and colleagues (McDonald, Störmer, Martinez, Feng, & Hillyard, 2013) tested this hypothesis by recording ERPs elicited by task-irrelevant lateralized sounds (i.e., exogenous cues) to investigate whether spatially uninformative sounds would activate the visual areas on the scalp. In Experiment 1 (Fig. 1.4), a spatially nonpredictive auditory cue preceded a contrast judgment task. Participants had to decide which one of two Gabor patches was higher in contrast. The preceding task-irrelevant sound was delivered at the location of one of them, and was non-informative as to which of the two targets was higher in contrast. However, in the majority of trials it had a fixed 150 ms cue-target stimulus-onset asynchrony (SOA), possibly causing it to act as a warning signal. Critically, even though the physical contrasts of the two Gabors were identical, participants judged the item presented at the location cued by the task-irrelevant sound as higher in contrast (Störmer, Green, & McDonald, 2009; for similar behavioral results). In the other experiments within the same series of studies, the visual task was replaced by auditory tasks in which no visual stimuli were presented at all, and the temporal predictability of sounds relative to the subsequent target was eliminated. The authors observed an enlarged positive deflection on the visual cortex contralateral to the sound’s location, in the 260–360 ms post-sound time window, that was present in all the task conditions. The presence of this Auditory-Evoked Contralateral Occipital Positivity (ACOP; Hillyard, Störmer, Feng, Martinez, & McDonald, 2016; for a review) suggests that the spatial processing of sounds was completed and that visual cortices were consequently activated, biasing the processing of visual information at the exogenously cued location. Coherently with this latter assumption, the bias in contrast judgement was found to correlate positively with the amplitude of the ACOP. Participants who showed greater ACOP amplitudes also had a higher probability of choosing the Gabor patch appearing at the sound location as having a higher contrast compared to the Gabor patch presented at the opposite location. The localization of this activation in the visual cortex was confirmed across several studies through source localization analyses. Specifically, the neural generators of the ACOP were identified in the ventral lateral extrastriate visual cortex (e.g., Feng, Störmer, McDonald, Martinez, & Hillyard, 2014; Hillyard et al., 2016; McDonald et al., 2013; Störmer, McDonald, & Hillyard, 2009).

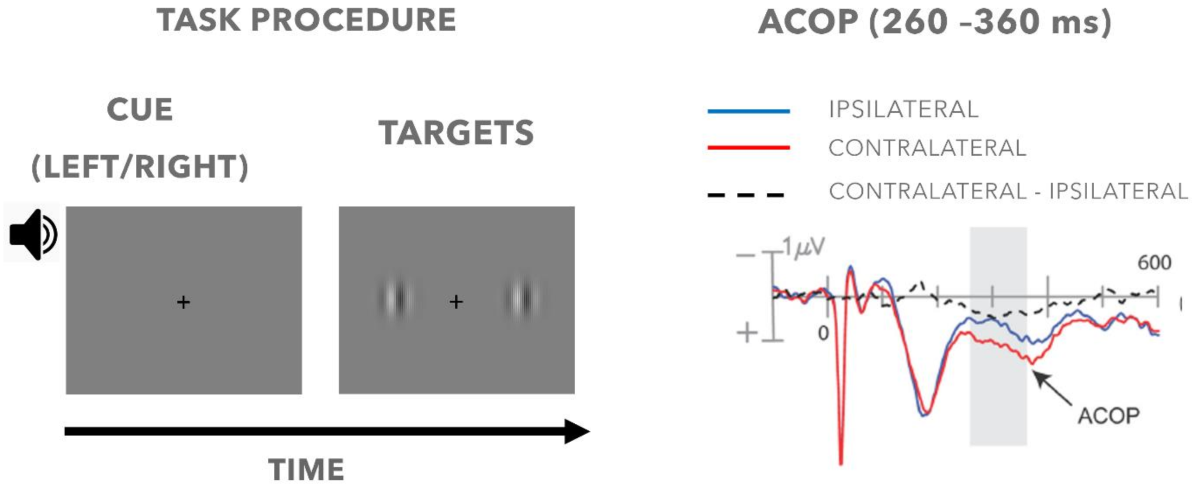

Fig. 1.4. Procedure and sound-elicited ACOP waveforms (260-360 ms) from Experiment 1 of McDonald et al. (2013).

Further evidence of ACOP and visual enhancement correlation has been described by Feng and colleagues (Feng et al., 2014). In this study, lateralized task-irrelevant auditory cues preceded a masked forced-choice letter discrimination task (T vs. L). The location of the cue and the letter could be either the same (valid trials) or the opposite (invalid trials) with the same probability, making the sounds non-predictive of the location of the target (as well as of timing or identity). The authors observed that, in validly-cued trials with incorrect responses, the ACOP amplitude was eradicated compared to trials in which observers made a correct discrimination. In invalidly-cued trials, a significant ACOP was observed independently from the outcome of the task. These findings indicated that auditory distractors may trigger spatially specific facilitation mechanisms that enhance visual processing at the exogenously cued location (valid trials) but does not impact visual discrimination at other locations (invalid trials). This hypothesis was recently confirmed in another exogenous cueing task. Keefe, Pokta, and Störmer (2021) explored whether cross-modal orienting of exogenous attention results in visual-cortical facilitation in the attended portion of space, or inhibition in the area that is unattended. Participants discriminated the direction of rotation (clockwise or counterclockwise) of a masked Gabor patch target. An auditory distractor preceded the visual target. The sounds could be either lateralized or not, and the central distractor was used as a baseline condition, as it was assumed that it would not evoke lateralized shifts of attention. Thus, any increases above this baseline neural activity and behavioral performance could be taken as evidence of facilitation at the attended location, whereas any decreases below this baseline were interpreted as evidence of inhibition at the opposite location. An increase in contralateral parieto-occipital cortex activity was observed, suggesting that exogenous cuing improved visual perception by enhancing the processing of events occurring at the cued location. In contrast, activity in the ipsilateral hemisphere was similar to the central condition baseline.

In conclusion, the ACOP seems to index a boost of early cortical processing at the location of a lateralized task-irrelevant sound that is aimed at supporting the processing of subsequent visual targets. This indicates that task-irrelevant sounds can influence visual cortex sensitivity in a spatially selective way, to adaptively tune the selection of potentially significant stimuli in the visual processing pathway. Interestingly, exogenous cuing effects have been observed to be elicited regardless of the sensory modality of the cue, producing similar behavioral benefits. Recently, it was also observed that exogenous cuing effects elicited by auditory and visual task-irrelevant stimuli are mediated by similar cortical mechanisms.

1.9.2. THE VISUAL CONTRALATERAL OCCIPITAL POSITIVITY (VCOP)

As well as lateralized sounds eliciting a positive deflection over contralateral visual cortex, labelled ACOP, visual onsets were observed to elicit a similar biasing of visual-spatial attention in anticipation of an incoming visual stimulus (Störmer, McDonald, & Hillyard, 2019). Störmer et al. (2019) asked participants to evaluate the brightness contrast of bilateral Gabor patches that followed a lateralized visual cue (Fig. 1.5). They then compared the neural activity elicited by the visual cue in that study to the ACOP observed in McDonald et al. (2013; Fig. 1.4). The location of the cue was non-predictive of the contrasts and orientations of the right and left Gabor patches. In the majority of trials, after a SOA of 134 ms following the cue, the Gabor patches appeared simultaneously, and participants were instructed to indicate, via a button press, the orientation (vertical vs. horizontal) of the Gabor patch that appeared to be higher in contrast. In some trials the cue was not followed by the targets, or was followed by Gabor patches after a longer delay. The cue-elicited neural activity analyses were conducted on these two conditions alone, that represented one third of the whole number of trials.

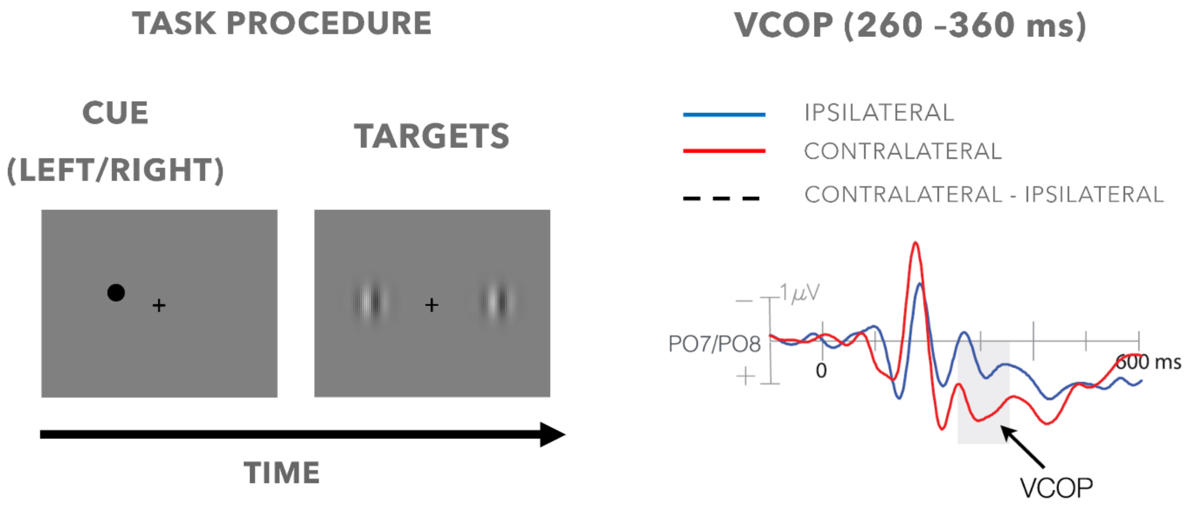

Fig. 1.5. Procedure and Visual Contralateral Occipital Positivity (VCOP; 260-360 ms) from Störmer et al. (2019).

The findings showed that visual and auditory cues elicited a sustained positive deflection over the contralateral visual cortex. These neural modulations were correlated with individuals' evaluations of brightness contrast of the co-localized visual targets, supporting the hypothesis that exogenous attention acts mainly as a cross-modal system and that the ACOP has its visual counterpart. This was labelled the VCOP (Visual Contralateral Occipital Positivity) and, together with the ACOP, has been suggested to index a common neural biasing signal of exogenous spatial attention in the visual areas. For instance, (a) their impact on behavioral responses to subsequent targets appeared to be similar. Indeed, the target appearing at the same location of the visual cue was judged as higher in contrast relative to the Gabor patch at the opposite location; (b) the latencies and scalp distributions of VCOP and ACOP are also similar (~260 ms). The similarity in latencies and scalp distributions have also provided evidence against the claim that the VCOP could reflect low-level sensory processing of the cue instead of an attentional biasing mechanism, as auditory stimuli elicited a similar pattern of neural activity. In summary, exogenous spatial attention elicits similar attentional biasing mechanisms in the visual processing pathways when driven by either visual or acoustic distractors (Störmer et al., 2019). However, to our knowledge, whether VCOP reflects an automatic mechanism of exogenous orienting or it is vulnerable to task demands is still unexplored.

1.9.3. TASK DEMANDS COUNTERACTING ATTENTIONAL CAPTURE BY EMOTIONAL SCENES

The prioritized allocation of attention to emotional novel stimuli results in emotional distractors affecting performance more than neutral ones in a variety of visual and acoustic tasks, as often measured in terms of interference costs (i.e., a slowing down of response times) in a concurrent task. Interference effects indicate that a distractor was prioritized in such a way that it was selected over task-relevant elements. What seems to emerge, however, is that emotional processing is not entirely automatic, since a combination of bottom-up and top-down factors may play a role in determining the extent to which attention will be allocated to task-irrelevant emotional events at the expense of goal-directed behavior (e.g., Micucci et al., 2020). For example, it was observed that the type and level of processing load might affect emotional interference effects (Tavares, Logie, & Mitchell, 2016). Tavares and colleagues (2016) used neutral or negative distractor images to explore their impact on performance in a perceptual load task and a working memory load task. The negative or neutral distractor was surrounded by a set of letters, including a target letter (X or N). The set size of the letter array could be either three (low load condition) or six letters (high load condition). The participants' task was to identify whether the target letter was an X or an N. In the WM load task, the memory set consisted of either one digit (low load) or six digits (high load). During the delay interval, participants saw the distractor image and a target letter (X or Z) appearing in a random position in proximity to the scene. Participants had to indicate the identity of the letter. Next, a memory probe screen consisting of a single digit appeared, and the task was to report whether that digit was in the original array or not. The presence of an unpleasant picture prolonged RTs compared to neutral scenes only in the low perceptual load, but not in the high perceptual load condition. The opposite pattern of results was observed on the attentional task presented during the delay interval of the WM task. In the low working memory load no difference was observed when unpleasant vs. neutral distractors occurred, but RTs were significantly slower for trials containing negative compared to neutral distractors in the high load trials. No disruptive effects of emotional processing were observed on WM, as similar error rates emerged in the WM task in the presence of neutral and emotional distractors.

1.10. THE AIM OF THE PRESENT RESEARCH

What emerges is that some stimuli have the intrinsic ability to be processed even if they are task-irrelevant, possibly interrupting task-related processes. Examples of powerful sources of distraction are acoustic and visual cues, and emotional scenes. Are we inevitably distracted by highly salient stimuli? Prior research has indicated that, under some circumstances, distractor processing might be mediated by task demands. The present work is focused on how endogenous spatial attention and visual working memory load affect the visual cortex response to distracting sounds or visual stimuli (i.e., ACOP and VCOP), and the allocation of attention to affective scenes.

(a) Endogenous spatial attention has been observed to affect the exogenous cuing effect (Santangelo et al., 2007). Task-irrelevant stimuli may go unnoticed when they fall outside the current focus of attention. However, it is not clear at which stage endogenous attention might interrupt the processing of sudden salient distractors. Prior research has identified two ERP components, namely ACOP and VCOP, as indexes of a spatially specific attentional biasing mechanism that is characterized by a transient visual-cortical enhancement induced in the opposite hemisphere to the location of a distractor. It is of note that, so far, no studies have examined whether ACOP and VCOP are modulated by endogenous spatial attention. Even though it was initially claimed that they might reflect an automatic process, (a) the ACOP modulation was suggested to be mediated by task set, and (b) the latency of the visuo-cortical change seems to be too late for it to index an automatic process. Earlier evoked potentials are usually attributed to sensory-driven brain activity, which is more likely to be reflexive, but changes in cortical activity with a latency larger than around 100 ms are attributed to attentive and post-attentive stages, which are usually influenced by contextual factors (Hillyard et al., 2016). Reduced or eliminated ACOP and VCOP should be observed if processing resources are prevented from being allocated to distractors occurring outside the focus of endogenous attention, demonstrating that having endogenous attention elsewhere engaged is sufficient to reduce or eliminate the visual-cortical enhancement elicited by acoustic and visual distractors.

Moreover, a dissociation in the vulnerability of visual-cortical enhancement elicited by acoustic and visual distractors to endogenous attention might be indicative that auditorily and visually elicited exogenous spatial attention are not part of the same attentional biasing mechanism in the visual processing pathways, but that they rely, at least partially, on distinct processes (Störmer et al., 2019).

(b) Evidence of VWM load effects currently applies to situations where interference comes from stimuli falling within the attentional set of the observer (i.e., foils). It is still unclear whether or not VWM load might also determine whether salient task-irrelevant stimuli will capture attention. According to the perceptual load hypothesis of VWM load effects, conditions of high VWM load lead to reduced processing of task-irrelevant stimuli due to early selection mediated by the engagement of early visual areas in the maintenance of visual information in WM. Since it has been shown that VWM recruits sensory processing areas to maintain visual information online (Harrison & Tong 2009), in Experiments 1 and 2 we investigated whether visual working memory load affects the attentional biasing observed over the visual cortex driven by either visual or acoustic distractors (Störmer et al., 2019). In line with the perceptual load hypothesis, ACOP and VCOP could be abolished or reduced if visual perceptual resources are employed to store information in VWM. Moreover, emotional processing has been observed to be affected by perceptual and verbal WM load (Tavares et al., 2016). In Experiment 3 we explored whether interference by pleasant pictures is modulated by VWM load.

CHAPTER 2 – THE EFFECTS OF ENDOGENOUS SPATIAL ATTENTION AND VISUAL WORKING MEMORY LOAD ON DISTRACTION

2.1. EXPERIMENT 1: EXOGENOUS ORIENTING TO ACOUSTIC DISTRACTORS

2.1.1. AIMS AND HYPOTHESES

The goal of Study 1 was to examine the effects of VWM load and endogenous spatial attention on the processing of acoustic distractor stimuli, as reflected in electrocortical activity (ACOP). We were aimed at exploring whether attentional orienting to distracting sounds is automatic or, rather, affected by task demands, and at which stage. An additional analysis was included to explore the modulation of the early modality-specific stage of sound processing, namely the frontal N1 (Feng et al., 2014). The N1 is a typical auditory-evoked ERP component peaking at 100-110 ms in the fronto-temporal areas, characterized by a more pronounced negativity over the hemisphere contralateral to the sound location and reflecting modality-specific sensory processing within the auditory cortex (Feng et al., 2014; McDonald et al., 2013).

Participants were actively engaged in a lateralized change detection task, and during the retention interval a task-irrelevant lateralized sound was delivered. The ACOP amplitude was analyzed as a function of the correspondence of sound's location with the cued side, and of the VWM load.

(a) According to the cross-modal view of the interactions between endogenous and exogenous attention (Chica et al., 2013; Santangelo et al., 2007), attentional capture by sudden sounds could be reduced when endogenous attention is directed towards a different direction by a previous central cue. This could indicate that visual-cortical enhancement elicited by acoustic distractors is not automatic.

(b) As ACOP indexes a visual cortex response to a lateralized sound, a reduced or annulled sound-elicited visual-cortical enhancement could be observed when VWM resources are overloaded compared to a condition in which VWM capacity is taxed less.

(c) A reduced auditory N1 under high compared to low VWM load was recently observed (Simon, Tusch, Holcomb, & Daffner, 2016) using a different task (it involved the maintenance of target letters, making the assimilation of this manipulation to VWM ambiguous; Luck & Vogel, 2013). In the present study, a reduced N1 might indicate that having VWM resources taxed by a concurrent VWM task limits the early processing of auditory distractors, indicating that VWM load effects are mediated by cross-modal mechanisms.

2.1.2. METHODS

PARTICIPANTS. A total of 18 volunteers (7 women) took part in the study. Ages ranged from 19 to 36 years (M = 24.11 years, SD = 4.14 years). The sample size was selected based on a survey of previous ACOP literature (e.g., Feng et al., 2014; Matusz et al., 2016; McDonald et al., 2013; Störmer et al., 2009; Störmer, Feng, Martinez, McDonald, & Hillyard, 2016). All participants had normal or corrected-to-normal vision and hearing, and none of them reported current or past neurological or psychopathological problems. All participants provided written informed consent in accordance with the Bioethics Committee protocols of the University of Bologna, and the experiment was conducted in accordance with the tenets of the Declaration of Helsinki. Participants had no previous experience with this task.

APPARATUS AND STIMULI. Participants were seated with a chin rest in a comfortable chair in an electrically shielded room. Visual stimuli were presented on an LCD computer screen (ViewSonic XG2530; 100 Hz refresh rate; 1280 × 768 pixels) placed at a distance of 60 cm from participants. Auditory stimuli were delivered through a pair of external loudspeakers (Trust Arys, 4 Ohm, 28 W) positioned to the left and right sides of the monitor. Visual and auditory stimuli were presented using the E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). All stimuli appeared on a gray background. A small black cross (0.67° x 0.67°) marking the center of the display was present during the whole trial. The cue consisted of a white arrow (1.4° x 0.3°) positioned 1.4° above the fixation cross. Memory array consisted of one or four squares per hemifield (each square measuring 1.1° x 1.1° of visual angle, distanced from the next square by at least 2°) whose color was selected randomly from a set of 7 possible colors (Red = RGB 255 0 0; Dark Green = 0 130 60; Blue= 0 0 255; Yellow = 255 255 0; Brown = 139 69 19; Cyan = 0 255 255; Green = 0 255 0). Squares could appear within an imaginary rectangular box, centered 3° from the screen center (to the left or right side), and measuring 4° horizontally and 10° vertically. The task-irrelevant sound was a pink noise burst (500 –15,000 Hz, 78 dB SPL, 83 ms duration with 5 ms rise and fall ramps) delivered unilaterally from one of two speakers placed to the left and right sides of the monitor.

PROCEDURE. A schematic illustration of a sample trial is depicted in Fig. 2.1. The experiment consisted of a lateralized change detection task (e.g., Vogel & Machizawa, 2004). Each trial began with the cue arrow (200 ms), indicating the hemifield that participants had to remember (left or right, with the same probability). Then a blank display remained on screen for a randomly jittered interval of 400 to 500 ms[1]. After this interval, the memory array appeared in each hemifield, and participants were instructed to memorize the squares from the cued side and to ignore the other side entirely. The number of squares was always the same on both sides of the screen. The same hemifield could never be cued for more than 5 consecutive trials. After 900 ms or 1200 ms (with the same probability) from the offset of memory array, the task-irrelevant sound was delivered

---

[1] Because of a technical error in the program, for the first three participants the interval duration was set at 400 ms. We decided to include those subjects in the final sample because the impact of the different cue-memory array interval duration on main CDA and ACOP results was negligible.

randomly from the speaker placed beside the cued side of the screen, or from the one placed beside the uncued side (50% each; 50% left, 50% right). Participants were clearly informed that the sounds were task-irrelevant. Sounds were delivered from the same speaker for a maximum of 4 consecutive trials, to avoid the learning of contextual regularities. To keep the retention interval duration at 1800 ms every time, trials in which the sound occurred 900 ms after the memory array had another interval of 900 ms; for the remaining trials the second interval lasted 600 ms. At the end of the retention interval the probe display appeared. It consisted of squares located only on the side that had been cued in the original array and stayed on screen until a response was given. In half of the trials the colors were identical to the memory display (‘no change’ trials), in the remaining trials one of the colors was different (‘change’ trials). Participants responded by pressing one of two keys (“b” or “h”) on a standard Italian keyboard that was placed in front of them, with one of the keys associated with a ‘change’ response, the other with a ‘no change’ response. The key-response association was counterbalanced across participants. No feedback was given after the response. The same trial type (‘change’ or ‘no change’) was repeated for a maximum of 5 consecutive trials. After the response, the trial ended and the next trial started after a blank intertrial interval of 1000 ms.

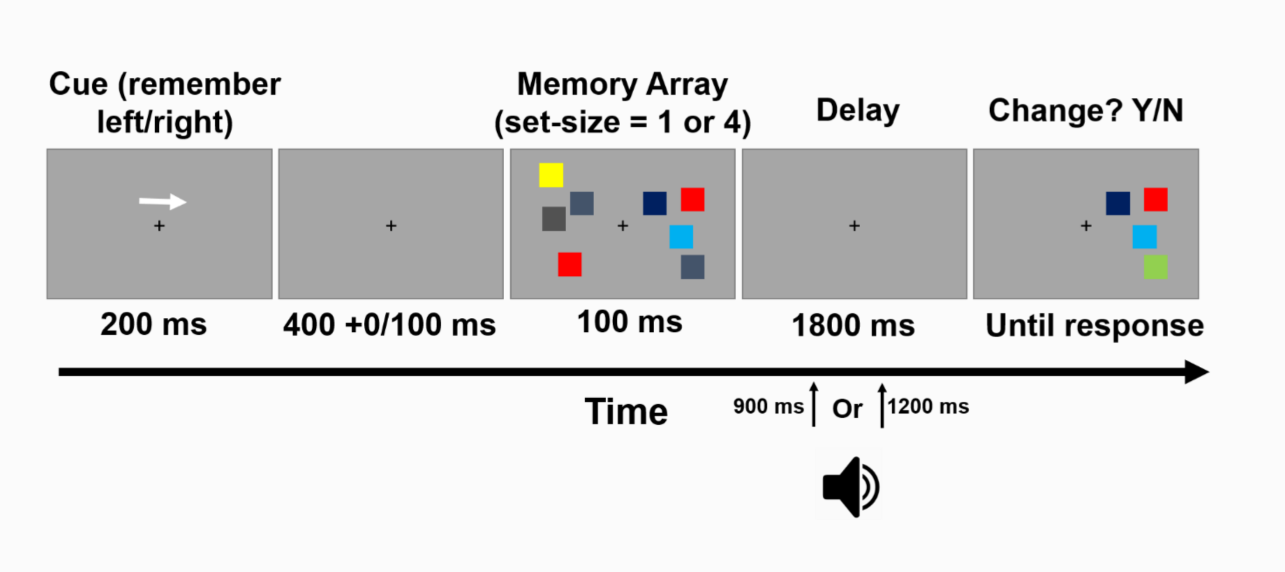

Fig. 2.1. Schematic illustration of the trial procedure. In the example a change trial from the high load condition can be seen. The auditory distractor could be delivered after 900 or 1200 ms from the memory array offset, randomly. Visually, only a gray background and central fixation cross were present during the whole retention interval.

The experiment was divided into two blocks, each one with a different set size[2]. In the low load block only one item per hemifield was presented in each trial, whereas in the high load block four items per hemifield were presented in each trial. Each block consisted of 336 trials, divided into 4 sub-blocks by brief pauses, the duration of which was decided by participants. An additional break was provided at the end of the first block. The total number of trials was 672, always preceded by a practice phase consisting of 20 trials (10 per load condition). The order of blocks was counterbalanced across participants. The whole experiment lasted about 1 hour, including breaks.

---

[2] For consistency with prior WM load literature (e.g., Gao & Theeuwes, 2020; Konstantinou et al., 2014; Tavares et al., 2016), the load condition was manipulated between blocks.

EEG RECORDING AND PROCESSING. Continuous EEG was recorded at a sampling rate of 512 Hz from 64 active sites using an ActiveTwo Biosemi system. Electrodes were mounted in an elastic cap positioned according to the International 10-10 system. Two additional sensors were placed near the outer canthi of the left and right eyes to monitor horizontal eye-movements (horizontal EOG), one below the participant's left eye to monitor vertical eye-movements (vertical EOG), and two were placed near the left and right mastoid process. An additional reference electrode located near Cz served as the reference during data acquisition. A hardware fifth-order low-pass filter with a −3 dB attenuation factor at 50 Hz was applied online. Off-line analysis was performed using Emegs (Peyk, De Cesarei, & Junghöfer, 2011). For the analysis of ERPs, the continuous EEG data were initially filtered (0.1 Hz high pass and 40 Hz low pass), and blink, horizontal, and vertical eye-movement corrections were carried out by means of an automated regressive method (Schlögl et al., 2007). Epoch files were then extracted and artifact detection was applied to trials and sensors by means of the absolute maximum amplitude, the standard deviation, and the absolute maximum temporal gradient of potential/field parameters at each epoch (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). Trials containing a high number of neighboring bad sensors were discarded; for the rest of the trials, sensors containing artifactual data were replaced by interpolating the nearest good sensors using a spherical spline function. Finally, data were re-referenced to the average of the right and left mastoid electrodes.

STATISTICAL ANALYSES. BEHAVIOR. Performance in the change detection task was examined in terms of response accuracy and an estimate of participants' visual working memory capacity. To obtain an averaged estimate of participants' visual working memory capacity, K values were computed for each load condition. We chose to use Pashler's formula (K= N[(hit rate – false alarms) / (1 – false alarms)]; Pashler, 1988) to obtain K, since it has been suggested as more appropriate for whole-display recognition versions of the change detection task (Rouder et al., 2011). Data were analyzed in a repeated measures univariate ANOVA in which a Huynh–Feldt correction was applied. Significant interactions were followed by post hoc tests.

ELECTROPHYSIOLOGICAL DATA. To collapse ERP data for visualization and statistical analysis, the regions and time intervals of interest were separately selected for the ERP components of interest, namely the CDA and the ACOP, as described below. Data from trials with incorrect responses were excluded from all the ERP analyses.

CDA ANALYSIS. CDA was calculated as the difference in waveform amplitude recorded over the contralateral and the ipsilateral hemispheres using cued side as a reference. For this purpose, ERP waveforms were collapsed across cued location (left/right) and hemisphere of recording (left/right) to obtain ERPs recorded over the contralateral hemisphere and over the ipsilateral hemisphere in relation to where the cue arrow pointed. CDA was measured as the mean amplitude over 4 pairs of parieto-occipital electrode sites (PO7/PO8, PO3/PO4, O1/O2, P3/P4[3]). Based on previous CDA literature (Hakim, Feldmann-Wüstefeld, Awh, & Vogel, 2020), a 200 ms interval preceding the onset of the memory array served as a baseline, and statistical analyses were carried out over the 300-900 ms time window locked to memory array onset. This time window was chosen a priori to include the part of the retention interval that preceded the acoustic interruption[4] (Luria et al., 2016). The CDA amplitudes were first analyzed in a repeated measures univariate ANOVA with factors of hemisphere (contralateral/ipsilateral to the cued side) and load (low/high). In all analyses a Huynh–Feldt correction was applied. Significant interactions were followed by post hoc tests.

---

[3] The set of sites included in the CDA analysis was selected from the scalp area that was used in previous literature (e.g., Hakim, Adam, Gunseli, Awh, & Vogel, 2019).

[4] As can be seen in Fig.1, in half of the trials the interval that preceded distractor interruption had a duration of 1200 ms, rather than 900 ms. For consistency purposes, we chose to select the same interval for both types of trial.

N1 ANALYSIS. The N1 was calculated as the difference in waveform amplitude recorded over the contralateral and the ipsilateral hemispheres, using sound laterality as a reference. For this purpose, ERP waveforms were collapsed across auditory stimulus location (left/right) and hemisphere of recording (left/right) to obtain ERPs recorded on the contralateral hemisphere and on the ipsilateral hemisphere. A cluster of 14 electrodes (FC1/FC2, FC3/FC4, FC5/FC6, C1/C2, C3/C4, C5/C6, and T7/T8) was used, and waveforms were corrected with respect to a 100 ms pre-sound baseline. By visually inspecting data, we observed that the N1 peak was at around 80-150 ms. The averaged amplitudes were first analyzed in a repeated measures univariate ANOVA with factors of sound laterality (left/right), hemisphere (contralateral/ipsilateral to side of sound), load (low/high), and equivalence with cued side (same/different). In all analyses a Huynh–Feldt correction was applied. Significant interactions were followed by post hoc tests.

ACOP ANALYSIS. The same procedure used to obtain the N1 was used to calculate the ACOP. The ACOP component was measured as the mean amplitude over 5 pairs of posterior electrode sites (P7/P8, PO3/PO4, P1/P2, P5/P6, P3/P4[5]), and waveforms were corrected relative to a 100 ms pre-sound baseline. The baseline period, similarly to the time window of interest, was selected to be consistent with previous literature (Feng et al., 2014; McDonald et al., 2013). The exact time interval for the ACOP analysis was then chosen based on when the ipsilateral and contralateral waveforms started to differentiate, and it corresponded to 280-500 ms. As our results did not differ between trials in which the auditory stimulus was delivered from the left or right speaker, we report the results collapsed between the two conditions. The averaged amplitudes were first analyzed in a repeated measures univariate ANOVA with factors of hemisphere (contralateral/ipsilateral to side

---

[5] The set of sites included in the analysis was chosen from the parieto-occipital region, based on previous ACOP studies (e.g., Feng et al., 2014).

of sound), load (low/high), and correspondence with cued side (same/different). In all analyses a Huynh–Feldt correction was applied. Significant interactions were followed by post hoc tests.

2.1.3. RESULTS

BEHAVIORAL PERFORMANCE. VWM task accuracy rates were significantly lower in the high load (M = .79, SEM = .02) than in the low load (M = .97, SEM = .01) condition, F(1, 17) = 176.863, $p < .001$, $\eta^2p = .91$[6]. The estimated amount of information maintained in VWM using Pashler's K (Pashler, 1988) increased significantly from the low (K = .99, SEM = .02) to the high (K = 2.84, SEM = .53) VWM load condition, F(1, 17) = 227.54, $p < .001$, $\eta^2p = .93$ (Fig. 2.2).

CDA. As shown in Figure 2.2, the ERP waveforms were more negative over the contralateral to the cued location compared to the ipsilateral hemisphere during the CDA time interval (300 – 900 ms), as described by the main effect of hemisphere, F(1, 17) = 7.94, p = .012, $\eta^2p = .32$. A significant interaction between hemisphere and load was also observed, F(1, 17) = 8.44, p = .01, $\eta^2p = .33$, with a more pronounced CDA amplitude in the high load condition. Specifically, the contralateral waveform was significantly more negative compared to that of the ipsilateral hemisphere in the high load condition, F(1,17) = 10.13, p = .005, $\eta^2p = .37$, but not in the low load condition, F(1,17) = 1.17, p = .296, $\eta^2p = .06$. When comparing the ipsilateral and contralateral waveforms separately in the two load conditions we observed no significant differences (all ps > .071).

---

[6] An additional repeated measures univariate ANOVA was conducted with the factors load (high, low) and correspondence between the initial cue and the location of the sound (same, different) to investigate possible exogenous cuing effects. No main effects or interactions with the correspondence of locations were observed either for accuracy or RTs (all ps > .256).

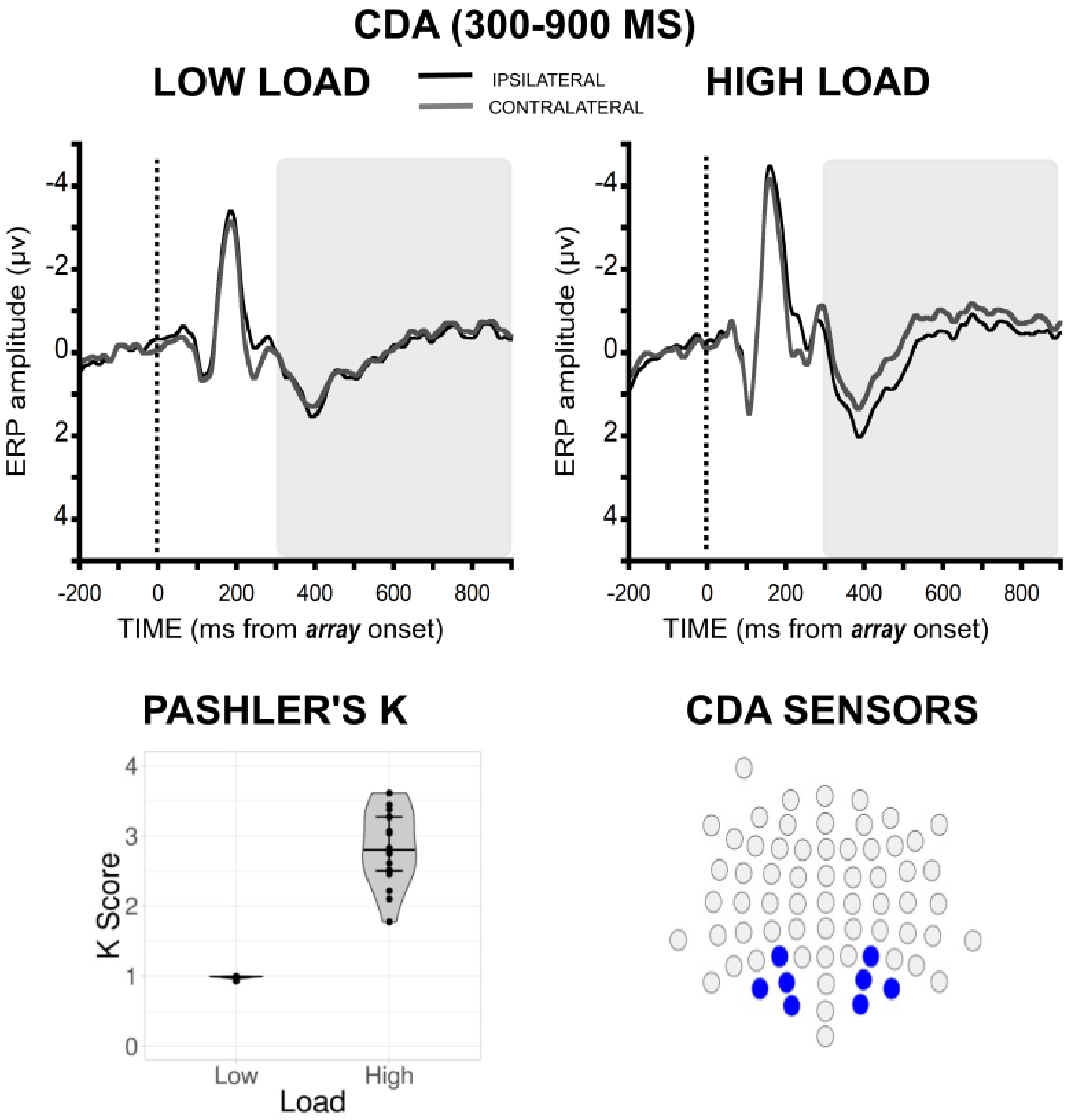

Fig. 2.2. CDA and behavioral results. The top row represents grand-averaged ERP waveforms for low and high load conditions analyzed in the CDA interval (300-900 ms) over 4 pairs of electrodes (colored in blue on the top-view electrode layout in the bottom right panel) placed ipsilaterally and contralaterally to the cued side of the display. The bottom left panel represents Pashler's K scores shown as a violin plot reflecting the data distribution. Results from each participant are shown as dots. A vertical bar indicates the 95% confidence interval determined by bootstrapping for each median.

N1. As shown in Figure 2.3, the ERP waveforms were more negative over the hemisphere contralateral vs. ipsilateral with respect to the location of the sound during the 80-150 ms time interval. The repeated measures univariate ANOVA we performed confirmed that the main effect of hemisphere was statistically significant, $F(1,17) = 15.17$, $p < .001$, $\eta^2 p = .47$, but no significant interaction with load or cued side factors was observed (all ps > .097).

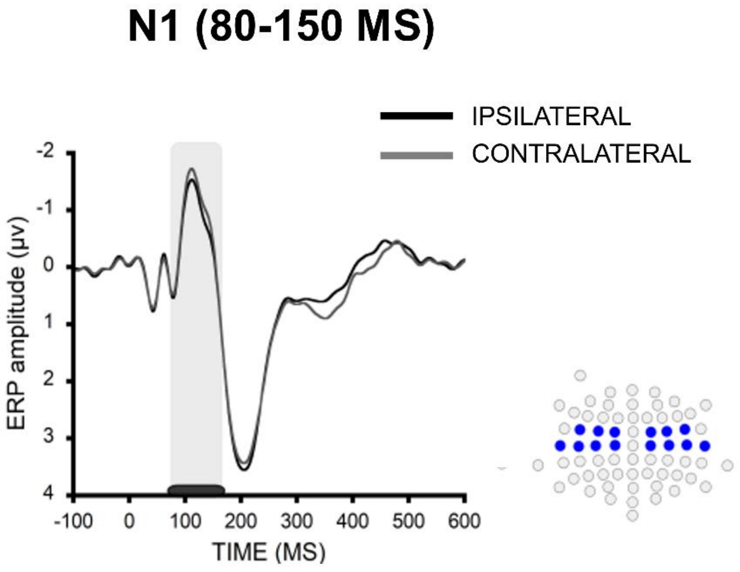

Fig. 2.3. Sound-elicited N1 waveforms averaged over 7 pairs of electrodes ipsilateral and contralateral to the sound are shown. The N1 interval (80-150 ms) is colored in gray. In the bottom right panel the selected electrodes are shown in blue.

ACOP. As shown in Figure 2.4, the ERP waveforms were more positive over the contralateral than the ipsilateral hemisphere in terms of sound location during the ACOP time interval (280 – 500 ms). The repeated measures univariate ANOVA we performed showed a main effect of hemisphere, $F(1, 17) = 38.24$, $p < 0.001$, $\eta^2 p = .69$, with a more pronounced positivity in the contralateral hemisphere compared to the ipsilateral one. The magnitude of this difference was modulated only by the correspondence factor, $F(1, 17) = 10.5$, $p = .005$, $\eta^2p = .38$, but no significant interaction between hemisphere and load, $F(1, 17) = .3$, $p = .592$, $\eta^2p = .02$, was observed. To examine this result in more detail, post-hoc tests were performed to compare the ipsilateral and contralateral ERP waveforms in each correspondence condition. These comparisons indicated that the ACOP was significant both when the sound occurred in same location as VWM contents, $F(1, 17) = 42.9$, $p < .001$, $\eta^2p = .72$, and when it occurred in the differing location, $F(1, 17) = 19.73$, $p < .001$, $\eta^2p = .54$, but that the amplitude of the contralateral vs. ipsilateral difference was more pronounced when the sound occurred in the same location. When comparing the ipsilateral and contralateral waveforms separately in the two correspondence conditions we observed no significant differences (all $ps > .17$).

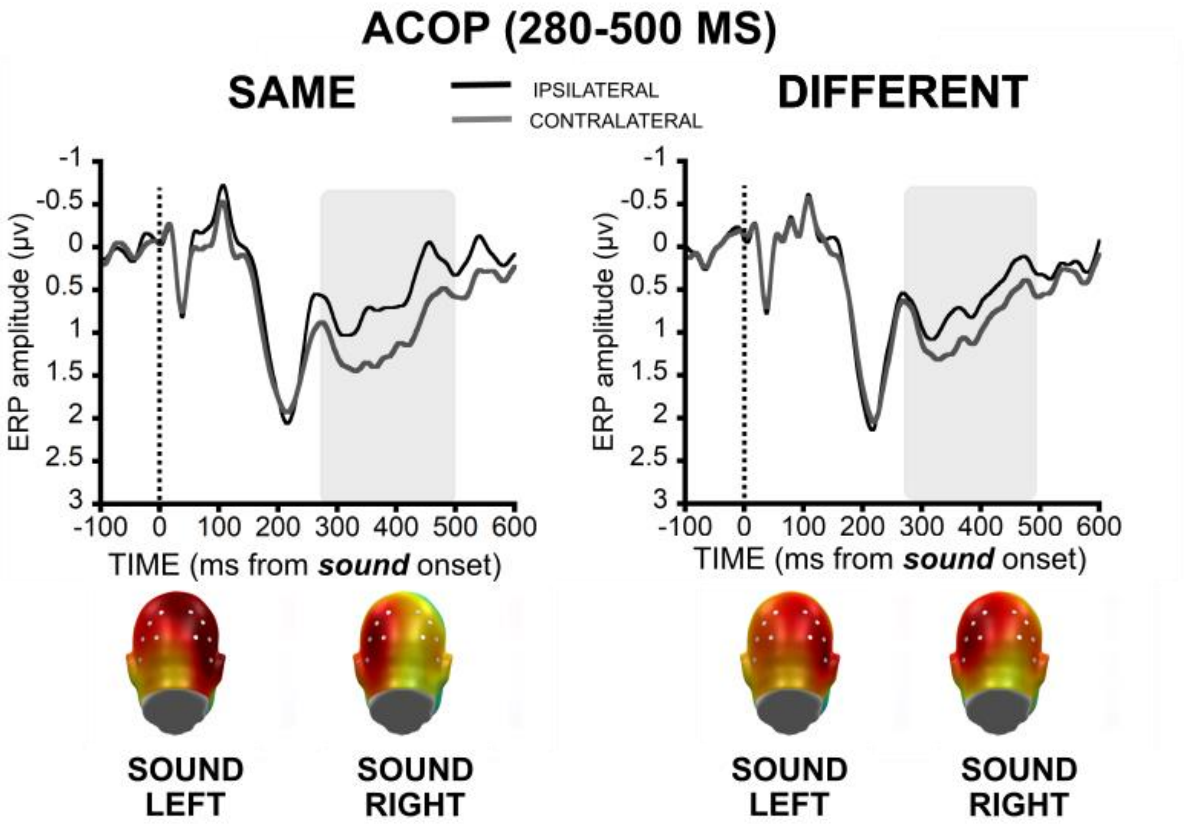

Fig. 2.4. Sound-elicited ACOP waveforms and scalp topographies. Grand-averaged ERP waveforms were averaged over 5 pairs of electrodes positioned ipsilaterally and contralaterally to the sound, marked in white over each topography. The ACOP interval (280-500 ms) is colored in gray. In the top left panel are waveforms that were averaged across trials in which the sound and cued locations corresponded. Below, scalp topographies of the ACOP interval are plotted separately for trials with left and right sounds. In the right panel, waveforms (top) and topographies (bottom), averaged across trials in which the sound occurred in the locations did not correspond, are shown.

2.1.4. DISCUSSION

Hearing a lateralized task-irrelevant sound while performing a visual working memory task elicited a typical auditory N1 in the 80-150 ms time interval, and a visual-cortical enhancement by exogenous spatial attention (i.e., ACOP) in the 280–500 ms interval, indicating that the incoming information is constantly analyzed even when entirely irrelevant for the task at hand. This is in accordance with the proposal that salient distractors capture attention and are processed quickly, rather than receive leftover processing resources from the processing of task-relevant stimuli, since attending to salient events may allow the system to avoid missing implicitly important information (e.g., for detecting danger or benefits in the outer world; Benoni & Ressler, 2020).

The sound-elicited activation of visual cortices[7] was attenuated when participants were remembering visual items that were placed in the opposite location to sounds. Our findings support the hypothesis that ACOP is not fully automatic, meaning that it is not a mechanism that is "[…] elicited identically under all possible task conditions and brain states" (Hillyard et al., 2016, p. 177). The relevance of this result relies on the fact that direct evidence of this cross-modal process not being fully reflexive in nature is weak (Hillyard et al., 2016; Matusz, Retsa, & Murray, 2016). Recent findings observed that statistical regularities in the location of task-irrelevant sounds eliminated the ACOP modulation in a passive listening context (Matusz et al., 2016). Specifically, task-irrelevant sounds affected visual processing and activated the visual cortex only when their location was unpredictable (Matusz et al., 2016). Moreover, in a recent study which used sounds as task-relevant targets, the ACOP disappeared when the spatial location of the sounds was not included in the task set (Retsa et al., 2020). However, the present study is the first that addresses the question of whether spatially-specific exogenous orienting elicited by acoustic events is affected by endogenous spatial attention. Even though ACOP was not fully eliminated here, we report that endogenous attention impacts on ACOP amplitude. This is also in line with the observation that

---

[7] We did not run any source localization analysis, however the latency and topography of the contralateral-minus-ipsilateral difference closely resembles the ACOP described in previous studies with neural generators localized in visual cortex (Feng et al., 2014; Matusz et al., 2016; McDonald et al., 2013; Störmer et al., 2016).

exogenous cuing effects are reduced when endogenous attention is directed elsewhere (Santangelo et al., 2007).

Differently from endogenous attention, VWM load had no impact on ACOP amplitude. Indeed, even though our behavioral and CDA results confirm that our load manipulation was successful, acoustic distractor processing was not affected by the set size of the memory array. Ample evidence of WM capacity load modulation over attentional selection has been described in literature (Lavie, 2010). Together, previous and current evidence could suggest that VWM capacity load exerts dissociable effects over distinct aspects of attention. Given the beneficial effect of orienting attention to a location in which an ecologically relevant event could occur, it is possible that the sound-elicited visual enhancement could be resistant to VWM capacity limitations. Similarly, VWM load was observed to have no effects on temporal attention (Zanto, Liu, Pan, & Gazzaley, 2020), or on the extraction of spatial regularities from the environment (Gao & Theeuwes, 2020). Discrepancies with previous literature could be reconciled by considering these spatial and temporal processes as evidence of the system's ability to extract information from the environment and use it adaptively to support behavior. For instance, proactively filtering out ecologically relevant objects while carrying out a mental task would be detrimental from an evolutionary perspective, as it would cause potential threats or rewards to be missed. Being constantly able to allocate processing resources to task-irrelevant but ecologically important events in our surrounding environment represents a more adaptive strategy for humans. Accordingly, the resistance of stimulus-driven attention effects (i.e., distraction) by salient objects even under mental load conditions could suggest that the attentional system recognizes the adaptive potential of some distracting stimuli, and treats them as essentially relevant (Benoni & Ressler, 2020). In contrast, the flanker effect largely reflects the role of attentional control (Von Bastian et al., 2020) rather than stimulus-driven selection, as it follows a failure in the inhibition of incongruent stimulus-response associations (Gil-Gómez de Liaño et al., 2016).

The early stage of task-irrelevant auditory stimuli processing (as indexed by the N1) seemed not to be affected, either by VWM load or by endogenous attention. This is in contrast with a previous study (Simon et al., 2016) that observed reduced auditory N1 under high compared to low VWM load. Differences that are intrinsic to the specific paradigms may explain these apparently controversial findings. In the study by Simon et al. (2016) participants were required to remember target letters, a manipulation that may tax the verbal WM subsystem (Baddeley, 1996; Baddeley & Hitch, 1974; Luck & Vogel, 1997); this task could interfere more with auditory processing than one requiring the storage of visual information. This would be compatible with Baddeley's model, which assumes the existence of separate storage systems (i.e., visuospatial store and the phonological loop) that are based on modality-specific codes. Retention of letters may employ the phonological buffer according to Baddeley and Hitch's working memory model. Notably, verbal load does not always interfere with attention to auditory stimuli. In a recent study (Golob, Winston, & Mock, 2017), it was observed that only spatial, but not verbal, WM load affected the spatial processing of auditory targets (even though their location was not response-relevant).

Another possibility is that early stages of auditory processing are mostly reflexive. Sanmiguel et al. (2010) manipulated WM load by comparing a 1-back WM condition with a no-memory control condition. Task-irrelevant sounds were concurrently delivered, and they could be frequent standard tones (80% of trials) or novel sounds (20%). Electrocortical markers of distraction caused by the novel sounds were analyzed, namely N1-enhancement/MMN, novelty-P3, and RON components. These waves are commonly used as markers of different stages of exogenous attention control: transient stimulus change detection that leads to attention capture (N1-enhancement/MMN);

exogenous orienting of attention (novelty-P3); and the reorienting of attention back to the task (RON), respectively (e.g., Friedman, Cycowicz, & Gaeta, 2001). Early stages indexed by N1-enhancement/MMN were not affected by WM load manipulation, suggesting that mechanisms related to change detection are not vulnerable to this top–down modulation, in line with several studies (e.g., Berti & Schröger, 2003; Otten, Alain, & Picton, 2000). However, WM load reduced the amplitude of the novelty-P3, albeit only in its later phase, in line with previous findings (Berti & Schröger, 2003). The RON was enhanced when WM was engaged (even though a decrease in RON amplitude was found in Berti & Schröger, 2003). Together, these data provided evidence for an initial stage designated to the analysis of the auditory input that is mostly reflexive, and a second stage, marking the effective orienting of attention, that is affected by WM load. Future studies will be needed to clarify whether early stages of auditory processing are sensitive to task demands or, rather, reflexive. The contribution of specific top-down factors in determining penetrability to top-down manipulations of the N1 (e.g., the nature of to-be-remembered material) should be further investigated.

Overall, the observation that passively-heard sounds during performance of a VWM task produce cross-modal visual cortex activation suggests that attention can be allocated exogenously to sounds, independently of their task-relevance. However, if there were an automatic process underlying ACOP modulation, one should not observe modulations caused by task demands (Moors & De Houwer, 2006); this was not the case. When endogenous spatial attention was directed elsewhere, modulatory effects on sound-elicited visual enhancement emerged, making it a critical factor in determining the degree of visual cortex activity triggered by the detection of the acoustic distractors.

2.2. EXPERIMENT 2: EXOGENOUS ORIENTING TO VISUAL DISTRACTORS

2.2.1. AIMS AND HYPOTHESES

In Study 1 we observed that the ACOP was affected by endogenous spatial attention but not by VWM load. In the present study, participants were engaged in the same version of the change detection task, but a task-irrelevant lateralized small dot appeared during the retention interval.

(a) If VCOP and ACOP are part of the same attentional biasing mechanism in the visual processing pathways, similar effects of endogenous attention might be observed on auditorily and visually elicited exogenous spatial attention. VCOP amplitude could thus be reduced when endogenous attention is directed towards a different location.

(b) For what concerns VWM load, because of the involvement of early visual areas, one might predict that the processing of a visual distractor, but probably not of an auditory one, is sensitive to VWM load. If this is the case, the VCOP amplitude could be reduced under high VWM load. Please note that, differently from Study 1, distractor modality is relevant here, as it corresponds with the modality that is employed by the task, probably enhancing the inherent relevance of the distractor.

2.2.2. METHODS

PARTICIPANTS. Because the design was the same as Experiment 1, we aimed to keep the sample size similar. A total of 21 volunteers were initially recruited for the study. Two of them were excluded because their accuracy rates were below 60% in the high load condition. Results from other two participants were discarded because more than 40% of their trials were rejected due to eye movements or overall artifacts after ICA correction. The final sample, therefore, consisted of 17 participants (11 women). Ages ranged from 18 to 35 years (M = 23.4 years, SD = 5.27 years). All participants had normal or corrected-to-normal vision, and none of them reported current or past neurological or psychopathological problems. All participants provided written informed consent in accordance with the Bioethics Committee protocols of the University of Geneva, and the experiment was conducted in accordance with the tenets of the Declaration of Helsinki. Participants had no previous experience with these task or stimuli.

APPARATUS AND STIMULI. Participants were seated in a comfortable chair in an electrically shielded room. Visual stimuli were presented on an LCD computer screen (60 Hz refresh rate; 1920 × 1080 pixels) placed at a distance of 80 cm from participants. The stimuli were presented using the E-prime 3.0 software (Psychology Software Tools, Pittsburgh, PA). All stimuli appeared on a gray background. The task and stimuli were the same as those used in Experiment 1, with the only exception of the distractor. The distractor was a single black dot (0.3° × 0.3°) presented on the right or left side.

PROCEDURE. The task was the same as that used in Experiment 1. The only exception was that, 900 ms or 1200 ms after the offset of the memory array the visual distractor appeared and stayed on screen for 67 ms. The total number of trials was still 672, always preceded by a practice phase.

EEG RECORDING AND PROCESSING. Continuous EEG was recorded at a sampling rate of 512 Hz from 64 active sites using an ActiveTwo Biosemi system. Electrodes were mounted in an elastic cap positioned according to the International 10-10 system. Two additional sensors were placed near the outer canthi of the left and right eyes to monitor horizontal eye-movements (horizontal EOG), one below and one above the participant’s left eye to monitor vertical eye-movements (vertical EOG), and two placed near the left and right mastoid process. An additional reference electrode located near Cz served as the reference during data acquisition. A hardware fifth-order low-pass filter with a −3 dB attenuation factor at 50 Hz was applied online. All analyses were carried out using the EEGLAB (Delorme & Makeig, 2004) and ERPLAB toolboxes (Lopez-Calderon & Luck, 2014), operating in the MATLAB (Mathworks, Natick, MA) environment. The EEG data were initially filtered (0.1 Hz high pass and 40 Hz low pass). Epoch files were then extracted and data were re-referenced to the average of the right and left mastoid electrodes. An Independent Components Analysis (ICA) was conducted on the epochs of interest (time interval ranging from -500 ms to 1500 ms after the onset of memory array and distractor, separately) to isolate and reject components related to blinks and saccades. Trials still containing artifacts caused by saccades not identified by the ICA were removed when the HEOG signal varied ±40 µV over a time interval ranging from -100 ms to 600 ms (0 = event onset), and artifacts caused by blinks (VEOG) were removed when the signal varied ±40 µV over a time interval ranging from -100 ms to 200 ms. Trials in which the artifacts not related to eye movement signal exceeded ±100 µV were excluded from all analyses (CDA epoch = -200 to 900 ms; VCOP epoch = -100 to 600 ms).

STATISTICAL ANALYSES. All the analyses were conducted following the procedure described in Experiment 1. Because data in the two experiments were collected across different groups of participants (and in different laboratories using different equipment), no direct comparison between the modulation of visual and auditory exogenous cueing of attention was conducted.

BEHAVIOR. Performance in the change detection task was examined in terms of response accuracy and an estimate of participants’ visual working memory capacity (Pashler’s K; Pashler, 1988), using the same procedure used in Experiment 1.

CDA ANALYSIS. The procedure described in Experiment 1 was used to isolate the CDA component. Based on prior studies (see Luria et al., 2016), the CDA was measured using a -200 ms baseline, and statistical analyses were carried out over the 300-900 ms time window locked to memory array onset. This time window was chosen a priori to include the part of the retention interval that preceded the acoustic interruption. The analyses were carried out on PO7/PO8 sensors, consistently with prior studies. The CDA amplitudes were first analyzed in a repeated measures univariate ANOVA with factors of hemisphere (contralateral/ipsilateral to the cued side) and load (low/high).

In all analyses a Huynh–Feldt correction was applied. Significant interactions were followed by post hoc tests.

VCOP ANALYSIS. The procedure described in Experiment 1 for the ACOP was used to isolate the VCOP component, but using the location of the visual distractor as reference. To our knowledge, the only study that analyzed the VCOP component (Störmer et al., 2019) recorded it over the PO7/PO8 sensors. For instance, these electrodes were chosen a priori for the current analyses. Waveforms were corrected relative to a 100 ms pre-sound baseline, consistent with previous literature (Störmer et al., 2019). The exact time interval for the VCOP analysis was then chosen based on when the ipsilateral and contralateral waveforms started to differentiate, and it corresponded to 250-500 ms. The averaged amplitudes were first analyzed in a repeated measures univariate ANOVA with factors of hemisphere (contralateral/ipsilateral), load (low/high), and correspondence with cued side (same/different). In all analyses a Huynh–Feldt correction was applied. Significant interactions were followed by post hoc tests.

2.2.3. RESULTS

BEHAVIORAL PERFORMANCE. The efficacy of our load manipulation was confirmed by the fact that the estimated amount of information maintained in VWM using Pashler's K score increased significantly from the low (K = .98, SEM = .0) to the high (K = 2.37, SEM = .12) VWM load condition, F (1,16) = 137.83 , $p < .001$, $\eta^2p = .896$. In addition, accuracy in the change detection task was lower in the high (M = .73, SEM = .01) compared to the low load block (M = .97, SEM = .0), F (1,16) = 344.67 , $p < .001$, $\eta^2p = .96$.

CDA. The ERP waveforms were more negative over the contralateral to the cued location compared to the ipsilateral hemisphere during the CDA time interval (300 – 900 ms), as confirmed by the main effect of hemisphere, F(1, 16) = 6.34, $p = .023$, $\eta^2p = .28$. A general load effect was observed as well, F(1, 16) = 8.1, p = .012, η^2p = .34. A significant interaction between hemisphere and load was also observed, F(1, 16) = 19.47, p < .001, η^2p = .55, with a more pronounced CDA amplitude in the high load condition. Specifically, the contralateral waveform was significantly more negative compared to that of the ipsilateral hemisphere in the high load condition, F(1,16) = 24.71, p < .001, η^2p = .61, but not in the low load condition, (p = .6). The negativity of the contralateral waveform was more pronounced in the high compared to the low load block, F(1,16) = 18.2, p = .001, η^2p = .53, but no significant difference in the ipsilateral hemisphere was observed (p = .25).

VCOP. The ERP waveforms were more positive over the contralateral than the ipsilateral hemisphere in the 250 – 500 ms time interval over the selected electrodes, F(1, 16) = 13.01, p = .002, η^2p = .45. The magnitude of this difference was modulated by the correspondence (Fig 2.5), F(1, 16) = 4.88, p = .042, η^2p = .23, and load (Fig 2.6) factors, F(1, 16) = 5.21, p = .036, η^2p = .25. A significant VCOP was observed when the distractor was in the same location as the one pointed-at by the cue, F(1, 16) = 25.86, p < .001, η^2p = .62, but not when it was in the opposite location, p = .684. The contralateral positivity was more pronounced when the distractor was in the same location compared to the different one, F(1, 16) = 14.81, p < .001, η^2p = .48, but the activity in the ipsilateral hemisphere was similar in the two conditions, p = .67. The VCOP was significant in the low load, F(1, 16) = 21.26, p < .001, η^2p = .58, but not in the high load condition, p = .48. However, the activity in the contralateral hemisphere was similar in the two conditions, p = .86. When comparing the ipsilateral waveforms, we observed an increased positivity in the high compared to the low load condition, F(1, 16) = 4.79, p = .044, η^2p = .23.

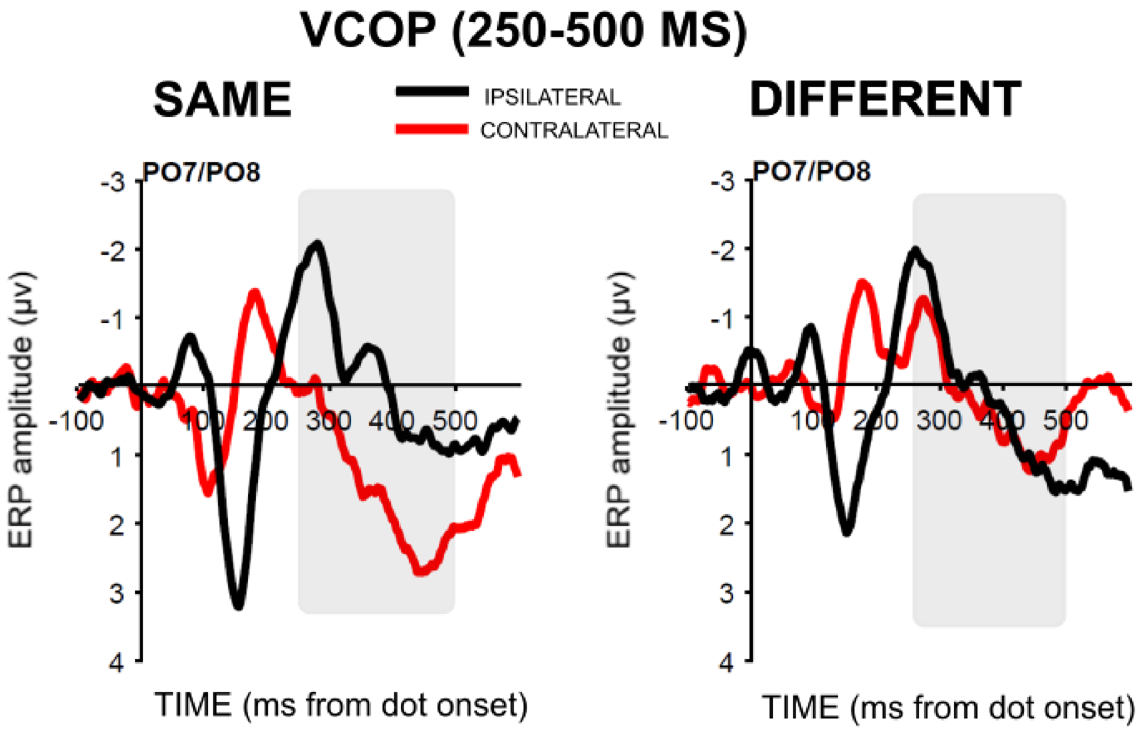

Fig. 2.5. Grand-averaged ERP waveforms in the VCOP interval (250-500 ms) averaged separately across trials in which the distractor (dot) and cued locations corresponded (left), and trials in which they did not correspond (right) are shown.

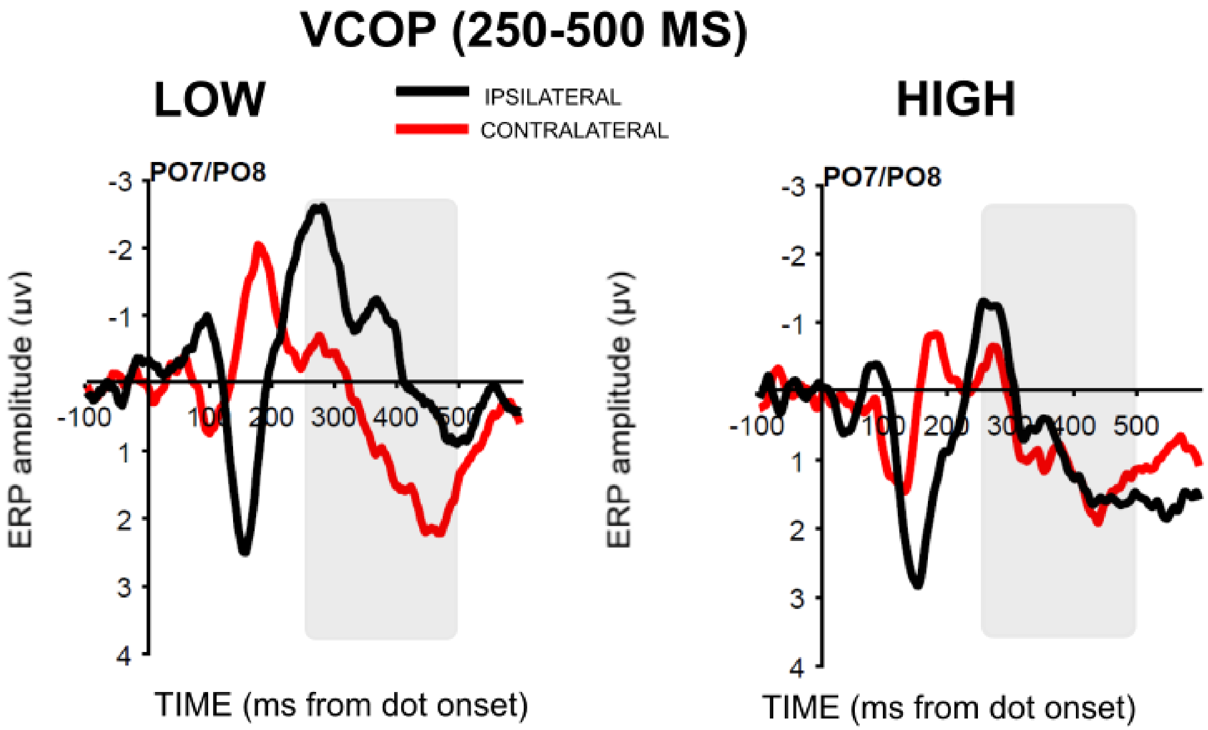

Fig. 2.6. Grand-averaged ERP waveforms in the VCOP interval (250-500 ms) averaged separately across trials in which the distractor (dot) appeared in the low load block (left), and trials in which it appeared in the high load one (right) are shown.

2.2.4. DISCUSSION

In a previous study we observed that endogenous spatial attention, but not visual working memory load, modulates acoustic distractor processing, as indexed by the auditory-evoked contralateral occipital positivity (ACOP). In the present study we explored whether or not endogenous spatial attention might also modulate visual distractor processing, as indexed by the visual-evoked contralateral occipital positivity (VCOP), that has been suggested to be the visual counterpart of the ACOP. In addition, we tested VWM load effects. In line with the perceptual load hypothesis, the absence of modulation of acoustic distractor processing in Experiment 1 could be due to the mismatch between to-be-remembered items and distractor modality. Our findings indicate that endogenous spatial attention affects the VCOP elicited by task-irrelevant distractors. Differently from Experiment 1, the VCOP was also affected by visual working memory load.

First of all, these findings are relevant as they are consistent with the evidence that endogenous spatial attention might affect exogenous distractor-elicited activation of visual cortices, and suggest that this happens regardless of the modality of the distractor. The visual distractor elicited a longer-latency (250-500 ms) positive potential shift that was larger over contralateral parieto-occipital scalp sites, similar to what we observed for auditory distractors (Experiment 1; ACOP). The ACOP and VCOP were suggested to be electrocortical markers of the allocation of exogenous visual-spatial attention to the spatial source of a task-irrelevant event (McDonald et al., 2013; Störmer et al., 2019). Previous findings supported the hypothesis that they index a modality-general biasing mechanism by which exogenous attention facilitates visual-cortical processing, and that they are part of a common neural biasing signal of exogenous spatial orienting. In fact, both ACOP and VCOP are elicited in exogenous cueing contexts and have similar latency and scalp distribution (Störmer et al., 2019). The results observed in the present study provide further supporting evidence for the hypothesis that these lateralized changes in cortical activity might be two facets of the same biasing mechanism. Indeed, ACOP and VCOP seem to be similarly affected by endogenous attention, even though the VCOP was fully eliminated when the location of the distractor was opposite to that indicated by a fully predictive endogenous arrow cue. Moreover, our findings suggest that this effect was driven by a modulation of the activity in the contralateral hemisphere. This is in line with the hypothesis that the biasing mechanism is caused by increased visual attention at the attended position, and that this results in enhanced activity in the contralateral hemisphere instead of suppression of an unattended location (Keefe et al., 2021).

Further studies could be addressed to determine if endogenous shifts of attention modulate exogenous orienting by enhancing the facilitation effect on visual-cortical processing when the distractor occurs at an endogenously cued location, or if facilitation is reduced when a distractor occurs at the opposite one.

Differently from Experiment 1, high VWM load eliminated the VCOP. This finding could be explained in terms of match between the perceptual resources engaged by the task and the distractor, but the interpretation of these results is subject to a few limitations due to the properties of our paradigm, that used visual distractors to activate the exogenous attention system during a visual task:

1. Structural interference. The modulation of distractor processing could be explained not only in terms of capacity consumption, but also of structural interference (SI). SI refers to the competition, imposed by anatomical constraints, occurring when two or more input sources occupy the same sensory channel because they engage the same perceptual mechanisms (e.g., Marteniuk, 1986; Swinnen, 1990). In our paradigm, distractor processing was performed during visual information maintenance, that was proposed to be supported by the early visual cortex (sensory-recruitment hypothesis; e.g., Harrison & Tong, 2009; but see Xu, 2017). For instance, if the maintenance of visual objects engages the early visual cortex, visual perceptual resources may not be directed to the processing of a subsequent visual distractor. Inhibition could be caused by anatomical constraints in perceptual areas, rather than consumption of attentional capacity. Future studies should address this issue by exploring the extent to which the engagement of low-level processing resources contributes to determine the abolishment of visual distractor-elicited activation of visual cortices under high VWM load.

2. The relevance of the distractor. In Experiment 1 the distractor was entirely task-irrelevant as it was non-informative regarding the location, the timing, or the identity of the task-relevant items, and it was also presented in a differently modality that could be completely ignored. In the current experiment: (a) the modality of the distractor was task-relevant and (b) its position was task-relevant as it corresponded to the area of the task. Compared to events occurring at locations that never contain task-relevant items, events falling inside the attentional window might receive heightened attention. In addition to increasing the relevance of the distractor, these factors may have enhanced the competition between the distractor and the target. The VCOP might be affected by a reduction of the available visual WM resources, possibly because the processing of a sudden visual distractor occurring inside the attentional window engages some active filtering processes that were improbable in the case of auditory distractors delivered during a visual task.

To summarize, the main significance of the present results is that they add evidence to the hypothesis that ACOP and VCOP might be two facets of the same biasing mechanism. Precisely, ACOP and VCOP were similarly affected by endogenous attention, even though the extent to which their amplitude was modulated varied across the two studies. Whereas the ACOP amplitude was only reduced, the VCOP was eliminated. This could be due to differences that are intrinsic to our paradigm and that could have affected measurement of the ERPs (e.g., match vs. mismatch of modalities). Further investigations are needed to address the issue of how the activation of visual cortices elicited by task-irrelevant visual stimuli and sounds might be mitigated by top-down factors. Indeed, a direct and quantitative comparison of top-down modulation of ACOP and VCOP would be essential to investigate, in a more controlled context, the link between these neural correlates of exogenous cuing, and their vulnerability to top-down control. The fact that, in the two studies described in the present dissertation, the ACOP and VCOP were analyzed in different groups of subjects, and that the details of the two experiments (e.g., stimuli eccentricities and EEG processing) were necessarily different, limit the comparability of the results of modulatory effects of VWM load and endogenous attention on the neural correlates of auditory and visual distraction. One caveat is that the way EEG data were processed in Experiment 1 compared to Experiment 2 was different. This choice was motivated by the specific design of the two experiments, that differed in distractor's domain. We reasoned that the detection of stimuli presented in the visual domain may elicit more spontaneous gaze shifts towards the stimuli even though participants were instructed to maintain fixation on the center of the screen, compared to lateralized acoustic distractors, and this could result in more eye-related artifacts. As the independent component analysis (ICA) correction for saccade activity allows to manage ocular artifacts and leave the underlying neural activity intact without removing data from all the trials in which eye blinks and eye movements are detected (Drisdelle, Aubin, Jolicoeur, 2017), we applied ICA as a method for ocular artifact correction. Importantly, ICA correction reduces the impact of artifactual voltages, but gaze shifts might also change the sensory input (i.e., changes in eye position may affect the visibility of a subsequent visual event; Lopez-Calderon & Luck, 2014). Since there are no visual events of interest immediately following the distractor, we think that this is not a limitation of primary relevance for the aims of the present study.

2.3. EXPERIMENT 3: THE MODULATION OF THE EMOTIONAL DISTRACTION

2.3.1. AIMS AND HYPOTHESES

Study 3 was aimed at exploring whether VWM load may affect emotional processing and behavioral distraction by emotional scenes. A dual-task paradigm was used here: a change detection task coupled with an orientation discrimination task. Differently from Studies 1 and 2, the VWM task was presented centrally, as was the orientation discrimination task. The orientation task appeared during the retention interval, and it was sometimes flanked, to the right or to the left, by a task-irrelevant neutral or emotional picture. The same orientation discrimination paradigm had already been used in a previous study (Micucci et al., 2021) that explored the behavioral interference elicited by emotional distractors. In that set of studies, it was observed that the frequency of presentation of task-irrelevant pictures could impact behavioral interference by emotional distractors. Precisely, emotional distraction was enhanced when scenes were presented in 20% of the trials (10% neutral, 10% emotional), compared to a high-frequency condition (80% of distractor present trials). Therefore, as the exposure to task-irrelevant novel emotional distractors was already observed to play a critical role in modulating further attention allocation, we decided to present task-irrelevant distractors only in a minority of trials (10% neutral, 10% emotional), to increase their inherent significance. Moreover, the lateralized presentation of distractors allowed us to reduce their relevance for the task, as scenes appeared in locations that could be completely filtered out (prior evidence indicates that even peripheral distractors elicit emotional interference effects; e.g., Calvo et al., 2015). This was also done to dissociate the effects of the attentional focus and VWM load, as the attentional zoom size may mediate the effects of VWM load on selective attention (Lee & Jeong, 2020). Distraction may occur at various levels:

1. Comparison between performance in the presence of neutral scenes compared to that in the absence of distracting pictures is informative as to how the mere appearance of a task-irrelevant scene diverts attention from an ongoing task.

2. Emotional distraction may be inferred, on the other hand, by comparing performance in distractor-present trials when the content is emotional vs. neutral. Any differences indicate that the content of a picture and its motivational significance was processed, and that further attention was allocated to emotional stimuli.

In addition to measuring the impact of an emotional distractor on performance in a task that occurred simultaneously, the present study was aimed at analyzing whether or not the occurrence of an emotional scene could disrupt VWM maintenance. In a recent meta-analytic review it was shown that there is limited support that performance in a WM task is affected by affective information (Schweizer et al., 2019). However, results are mixed, as some interference effects of emotional material on WM performance have been reported in literature (e.g., MacNamara, Ferri, & Hajcak, 2011). The relative salience of the task-irrelevant emotional stimuli used could have had a role in determining whether or not distraction was observed across studies. Indeed, emotional distraction is often explored by presenting observers with emotional facial expressions. Scene processing is more direct in conveying affective information, and interference effects that are induced by facial expressions are usually smaller compared to those caused by natural scenes (e.g., Thom, Knight, Dishman, Sabatinelli, Johnson, & Clementz, 2014). This distinction may influence the extent to which task-irrelevant emotional faces and scenes impact WM performance. Moreover, some studies examined emotional processing during WM maintenance in passive viewing contexts (e.g., Barley, Bauer, Wilson, & MacNamara, 2021). In these cases, it was suggested that emotional stimuli were attended to, as participants are exposed only to those pictures in that given moment, and are thus free to look at them (Codispoti, Ferrari, & Bradley, 2007). Differently, when participants are actively engaged in an unrelated task, the amount of resources that can be allocated to affective task-irrelevant stimuli may be reduced as they must be primarily allocated to the task at hand (Schweizer et al., 2019). Relative to the effects of VWM on emotional distraction, two main scenarios might be observed:

1. If VWM load interferes with the preferential allocation of attention to emotional scenes, then emotional distraction (emotional vs. neutral) in a concurrent perceptual task might be present under low, but eliminated under high, VWM load.

2. In line with previous literature, it is possible for emotional distraction to have an impact only on a concurrent perceptual task, but not on VWM maintenance. A dissociation between effects of affective stimuli on a perceptual and a VWM task might indicate that (a) the processing of the motivational significance of scenes resists under VWM load, but that (b) the WM system efficiently mitigates the impact of affective distractors on WM maintenance. This could lead to absence of effects of task-irrelevant emotional stimuli processing on the VWM task, and the disruption of behavioral responses in a concurrent perceptual task.

2.3.2. METHODS

PARTICIPANTS. Based on a survey of previous literature on emotional distraction during similar WM tasks in healthy participants (Schweizer et al., 2019; for a review), we decided to select a sample size of at least 20 participants. Since we expected to observe a high drop out rate because the experiment was run online (Sauter, Draschkow, & Mack, 2020), we initially recruited a total of 34 volunteers. 13 of them were excluded either because they abandoned the session before the end or because their accuracy rates were below 65% in one or both tasks. The final sample, therefore, consisted of 21 participants (13 women)[8]. Ages ranged from 21 to 38 years (M = 29 years, SD = 4.82 years). All participants had normal or corrected-to-normal vision, and none of them reported current or past neurological or psychopathological problems. All participants provided written informed consent in accordance with the Bioethics Committee protocols of the University of Bologna, and the experiment was conducted in accordance with the tenets of the Declaration of Helsinki. Participants had no previous experience with this task or stimuli.

APPARATUS AND STIMULI. Due to the restrictions imposed by the COVID-19 pandemic, each participant completed the experiment remotely from his/her own home, using his/her own laptop. The experiment was implemented with the OSWeb version of OpenSesame (Mathôt, Schreij & Theeuwes, 2012). Data collection was managed by JATOS (Lange, Kühn, & Filevich, 2015). Participants received a single link to the experiment to access the experiment and were instructed to conduct the experiment from their own computer alone and in a quiet room.

The experiment consisted of a combination of an orientation discrimination task (Micucci et al., 2020) and a change detection task (Lee & Jeong, 2020). All stimuli were displayed on a gray background. A small black cross marking the center of the display was present during the whole trial. The change detection task display always consisted of four squares, each subtending approximately 1° x 1° of visual angle, placed at the four vertices of an imaginary box measuring 3° x 3° that was presented at the center of the display. The array contained either four colored squares

---

[8] To overcome the restrictions imposed by the Covid-19 pandemic we opted for an online testing solution (see the "Apparatus and Stimuli" section for details). Web-based experiments offer great advantages (e.g., in terms of time and resource efficiency) but, at the same time, are prone to several limitations, like higher drop out rates compared to laboratory studies. Our design was aimed at preventing participants' drop out (e.g., we provided both written and video versions of the experimental instructions to allow participants to understand it on their own). Nevertheless, a few participants didn't understand the task and others quitted before the end due to personal factors (e.g., lack of motivation and/or distractions). Data acquisition might benefit from the implementation of incentive strategies (e.g., either paying participants or adding a progress bar, as gamification of the study seems to yield successful online data acquisition; Sauter et al., 2020), so future studies could consider to include similar protocols in the task procedure.

(high load) or a single colored square (low load) presented together with three empty placeholders. The colors were randomly selected from the same pool of colors used in Studies 1 and 2. Colors were never repeated within the memory array.

In the Gabor task, a Gabor patch was displayed centrally, and in some trials it was flanked by a distractor scene. The Gabor patch (sinusoidal gratings with a Gaussian envelope) subtended a 5.3° × 5.3° visual angle, and it could be horizontally or vertically oriented. The Gabor patches were created by overlapping two distinct patches with the same orientation but different frequencies (0.94 and 9.4 cycles per degree of visual angle, respectively). 32 pictures depicting erotic couples were used as emotional distractors, and 32 images representing people in a variety of daily indoor activities were used as neutral stimuli. Scenes were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) and from public domain pictures available on the Internet. Scenes were positioned either to the left or the right of the central Gabor patch, with a center-to-center distance between the distractor image and the Gabor patch of 4°. Erotic scenes had been used in a previous study (Micucci et al., 2020) and were selected as the most arousing based on a pilot study measuring subjective ratings, LPP amplitude changes, and skin conductance changes. Scenes and Gabor patches were equated in brightness and contrast to avoid potential confounds resulting from low-level visual properties of the images.

PROCEDURE. To start with, participants had to read the informed consent and to fill out a series of forms aimed at collecting personal details and medical history. After that, a few examples of neutral and emotional pictures were shown to them, to allow them to leave the study if they were disturbed by scene contents. These sample pictures were never used in the experimental phase. Immediately before the beginning of the experiment, participants completed a procedure that is validated to calculate the viewing distance they were to maintain during the whole task, based on the dimension of their display (Li, Joo, Yeatman, & Reinecke, 2020).

A schematic illustration of a trial is depicted in Fig. 2.7. Each trial began with a blank display containing only the fixation cross. After this interval, the memory array appeared and stayed on screen for 100 ms. The offset of the array was followed by an interval of 1500, 1650, or 1800 ms, randomly, during which only the fixation cross was visible. At the end of this interval, the orientation discrimination task was presented. The participants' task was to determine whether a Gabor patch was oriented vertically or horizontally, by pressing a button. In distractor-present trials, a neutral or erotic scene (10% of trials each, for a total of 20% of distractor-present trials) was presented simultaneously with the Gabor patch, appearing equally often in the left or right hemifield. Participants were explicitly informed that there would be a distractor in some trials and that it was task-irrelevant. Scenes occurred in the same location for a maximum of three consecutive trials, and distractors belonging to the same category (neutral or emotional) were not presented more than twice consecutively. The Gabor and the eventual scene remained visible for 150 ms, and were followed by another interval of 2000, 1850, or 1700 ms, depending on the duration of the previous interval. During this interval only the fixation cross was visible, and participants had to respond to the orientation discrimination task via button press ("k" or "m", with key-response association counterbalanced across participants). The total retention interval duration was 3650 ms every time. Finally, the probe display was presented. It consisted of a single square among three placeholders and stayed on screen until a response was given. In half of the trials the color was identical to that of the squares that occupied the same location in the memory display ('no change' trials); in the remaining trials it was different ('change' trials). Participants responded by pressing one of two keys ("a" or "z") on the keyboard, with one of the keys associated with a 'change' response, the other with a 'no change' response. The key-response association was counterbalanced across participants.

No feedback was given after the response. The same trial type ('change' or 'no change') was repeated for a maximum of three consecutive trials. After the response, the trial ended and the next trial started after a blank intertrial interval of 1000 ms.

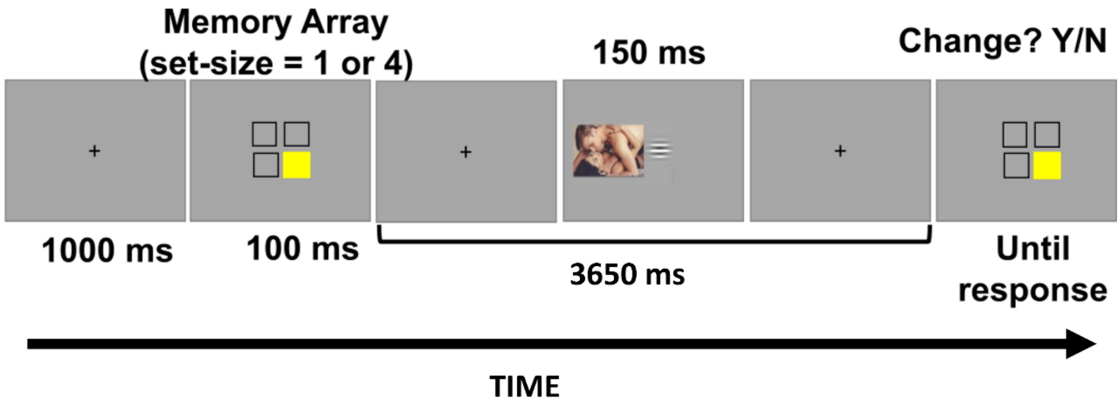

Fig 2.7. A schematic illustration of a low load, no change trial with an emotional distractor.

The experiment was composed of a low load and a high load block, varying only in the array set-size. In the low load block only a single colored square appeared along with three empty placeholders, whereas in the high load block four items were presented in each trial. Each block consisted of 96 trials, for a total of 192 trials. The order of blocks was counterbalanced across participants. The experiment started with a practice phase consisting of 40 trials (20 per load condition). The distractors used in the practice phase were not repeated during the experimental blocks. Only during the practice phase was feedback given at the end of each trial, informing participants as to the accuracy of both responses.

STATISTICAL ANALYSES. VWM TASK. Performance in the change detection task was examined in terms of response accuracy by means of a repeated measures univariate ANOVA with load (low/high) and distractor (absent/neutral/emotional) as factors. To obtain an averaged estimate of participants' visual working memory capacity, K values were computed for each load condition. Differently from Studies 1 and 2, a single-probed recognition paradigm was used in the present study, with only one target presented at a studied location and probed. Consistently with previous literature (Rouder et al., 2011), we used Cowan's formula to calculate the K score (K= N[hit rate – false alarms]; Cowan, 2001).

GABOR TASK. Trials with an incorrect response in the change detection task were excluded from all the analyses. Performance was examined in terms of response accuracy and reaction times (RTs), by means of a repeated measures univariate ANOVA with load (low/high) and distractor (absent/neutral/emotional) as factors. The analysis of RTs was critical in order to investigate the impact of distractors in this task, but the presence of outliers could strongly bias the results. We applied a nonrecursive shifting z score outlier screening procedure (Van Selst & Jolicoeur, 1994) by using the SPSS Production Facility implementation proposed by Thompson (2006). Within participants, trials with incorrect orientation discrimination or responses falling more than 2.173 standard deviations outside the mean across a single condition (as defined by load and distractor type) were excluded from the analysis. This criterion is suggested to be a valuable option to avoid data distortions when the number of trials per condition is quite small.

2.3.3. RESULTS

VWM. The efficacy of our load manipulation was confirmed by the fact that the estimated amount of information maintained in VWM using Cowan's K score increased significantly from the low (K = .9, SEM = .02) to the high (K = 2.31, SEM = .19) VWM load condition, F (1,20) = 64.8 , $p < .001$, η^2p

= .76. In addition, accuracy in the change detection task was lower in the high (M = .79, SEM = .01) compared to the low load block (M = .95, SEM = .01), F (1,20) = 78.48 , p < .001 , η^2p = .8.

Performance was also affected by the presence of emotional distractors (Fig. 2.8). A significant distractor effect was observed, F (2,40) = 3.88 , p = .029 , η^2p = .16. More errors were made in trials with emotional distractor compared to trials without distractor, F (1,20) = 6.35 , p = .02 , η^2p = .24, and with neutral distractor, F (1,20) = 4.92 , p = .038 , η^2p = .2, but no difference was observed between the two latter conditions, p = .857.

GABOR TASK. The overall accuracy was high (M = .95), indicating that the task was perceptually easy. Accuracy rates were not affected by either load or distractor type, all ps > .076. As shown in Figure 2.8, the appearance of an emotional image caused distraction in the orientation discrimination task. RTs to the Gabor task differed as a function of the distractor, F (2,40) = 9.77 , p = .001 , η^2p = .33. Specifically, RTs were slower when an emotional distractor was present compared to no distractor at all, F (1,20) = 11.09 , p = .003 , η^2p = .36, or a neutral one, F (1,20) = 15.12 , p = .001 , η^2p = .43, but no difference was observed between the two latter conditions, p = .282. in addition, RTs were slower in the high load block compared to the low load one, F (1,20) = 4.34 , p = .050 , η^2p = .18, but no interaction with the distractor condition was observed, p = .65.

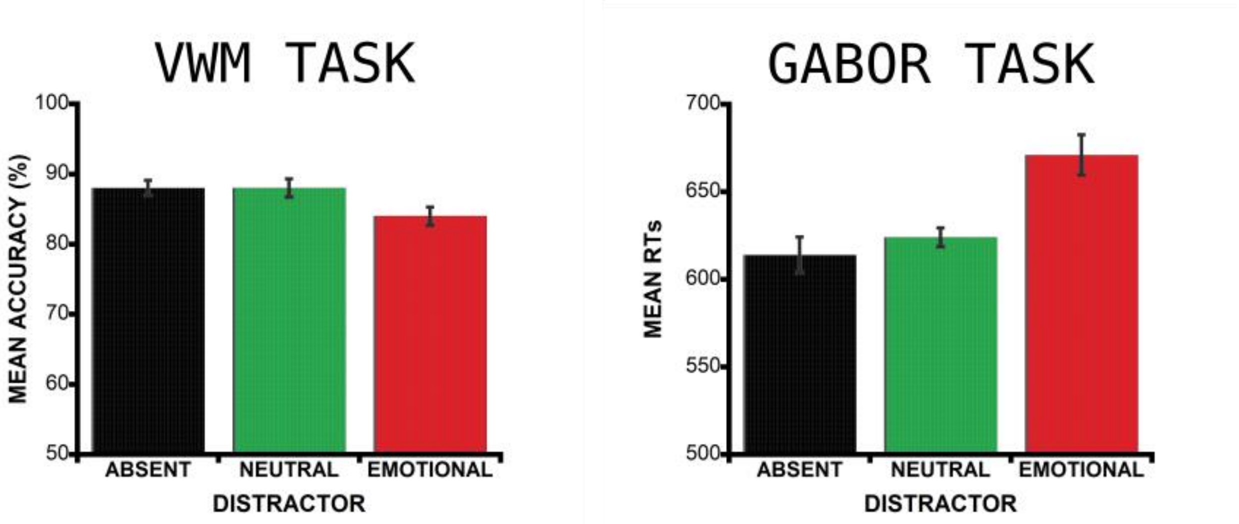

Fig 2.8. Left: accuracy averages and within-participant SEM (O’Brien & Cousineau, 2014) in the VWM task for distractor absent (black), neutral (green), and emotional (red) distractor trials. Right: RTs in the Gabor task and within-participant SEM.

2.3.4. DISCUSSION

We investigated whether the emotional content of pictures depicting erotic scenes captures attention during VWM maintenance in a dual-task context. To this end, participants were first shown a set of visual items and required to remember it. During the retention interval, they performed an interference paradigm aimed at assessing the impact of task-irrelevant scenes on the processing of concurrent task-relevant stimuli in an orientation discrimination task. At the end of the trial, they were tested on VWM maintenance through a single-probed recognition. The scenes were entirely irrelevant for the task, and appeared outside the attentional window, as both tasks were central but scenes appeared in the right or left hemifield (Lee & Jeong, 2020). The effects of emotional scenes were compared with those of neutral scenes, as well as with a condition without distractors. To isolate the effects of emotional factors from those related to the mere presence of a lateralized stimulus, we also compared interference elicited by the presence of neutral distractors to that in the absence of distractors. The presence of emotional scenes interfered with performance in both tasks, confirming that emotional events disrupt performance in an ongoing task in a more pronounced vein compared to neutral events. Emotional distraction was not affected by VWM load, but similar results were observed in the absence of a distractor compared to when a neutral scene occurred, suggesting that only highly salient objects obligatorily capture attention when participants are engaged in a VWM task.

Interference effects of emotional (as compared to neutral) scenes on both tasks indicate that processing resources were allocated to the scenes and that such resources were diverted from the discrimination task, even though participants were aware of the irrelevance of the pictures for the task and scenes occurred outside the attentional window. This finding supports the hypothesis that motivationally relevant stimuli (i.e., erotic scenes) are a special class of stimuli that mandatorily draw attention, disrupting the processing of concurrent targets, and the maintenance of visual stimuli in WM. VWM load and the inclusion in an attentional window are not factors that are able to inhibit the allocation of attention to pleasant pictures. Longer response latencies in the presence of emotional vs. neutral distractors were observed in a variety of attentional tasks, but evidence of interference with VWM performance was weak. In many cases, however, prior research explored the impact of emotional processing of two main types of pictorial stimuli: facial expressions and visual scenes. Emotional scenes are known to produce a stronger subjective experience and more pronounced ERP responses than facial expressions (e.g., Calvo et al., 2015; Thom et al., 2014), and thus the influence of scenes when they are task-irrelevant could be stronger compared to faces. Moreover, even when using scenes as distractors, low arousal categories of stimuli are often used (e.g., babies or puppies; Barley et al., 2021). A great body of research has proposed arousal as a fundamental parameter of motivational activation, indexing the intensity of the activation of the orienting system (Bradley & Lang, 2007). Accordingly, it is possible that the effects of affective processing on VWM are conditioned at the level of physiological arousal activation.

Prior findings regarding the modulation of emotional interference effects on the part of WM are mixed. Notably, a wide range of tasks (memory for digits, letters, or visual stimuli) and task-irrelevant stimuli (faces, scenes) have been adopted, making it difficult to provide a unitary explanation for all the findings. When memory for verbal material is overloaded, some evidence supporting the predictions of load theory has been reported. Enhanced attention to emotional scenes (Tavares et al., 2016) and faces (Holmes, Mogg, De Fockert, Nielsen, & Bradley, 2014) under high compared to low WM load has been observed. However, Pecchinenda and Heil (2007) observed that interference by emotional faces was unaffected by the degree of WM load. When emotional processing was assessed via changes in electrocortical activity, namely the late positive potential (LPP; Bradley, 2009; Hajcak, Weinberg, MacNamara, & Foti, 2012), it emerged that the processing of picture emotionality was not affected by a high WM load (Barley et al., 2021; MacNamara et al., 2011). In a recent study Barley et al. (2021) examined the effect of WM load on the processing of positive and neutral pictures by asking participants to perform a letter recall task with either a two-letter (low-load) or six-letter (high-load) string. Pleasant pictures depicted cute animals or erotic scenes, whereas neutral pictures depicted either faces or objects. A single picture was displayed alone in the retention interval for passive viewing. The affective modulation of the LPP was unaffected by WM load, that reduced only the overall LPP amplitude (i.e., the LPP elicited by positive and neutral pictures). Moreover, the presence of pleasant scenes did not impact WM recall performance (but it was observed that unpleasant images interfered to a greater extent compared to neutral stimuli in a previous study using the same paradigm but displaying negative pictures; MacNamara et al., 2011). In terms of affective modulation of the LPP, the same results described in Barley et al. (2021) were observed concerning the processing of negative pictures (MacNamara et al., 2011). The results from these two studies suggest that the emotional engagement elicited by emotional scenes, as indexed by changes in electrocortical activity, is not eliminated by mental load. In contrast, a study in which task-irrelevant facial expressions were displayed during a change detection task observed no behavioral distraction of emotion on VWM performance, whereas the affective modulation of the P1/N1 (early markers of visual processing) elicited by the distracting faces was reduced (Yang, Wang, Jin, & Li, 2015). This might be in line with the view that the extent to which affective processing disrupts VWM is conditioned at the level of physiological arousal activation, as faces elicit weaker responses compared to highly arousing scenes.

It is of note that in the present study performance in the presence of neutral scenes was not impaired compared to trials in which no distractor was displayed, indicating that differently from emotional scenes, neutral stimuli can be inhibited during a VWM task and when occurring outside the attentional focus. This dissociation indicates that the type of distractor used, and its relative salience, is critical in determining the impact of distractors on VWM and vice versa. Future studies could explore whether or not unpleasant scenes have similar effects (e.g., pictures of attack with weapons, mutilation, aggression, and illness), since dissociable effects of perceptual load in determining attention capture by irrelevant positive vs. negative stimuli were described in a prior study, using either erotica vs. mutilated body scenes or happy vs. angry faces (Gupta, Hur, & Lavie, 2016). High perceptual load limited interference from the negative valence distractors, but had no effect on the positive valence distractors, suggesting that valence may mediate vulnerability to perceptual load. A relevant outstanding question might refer to whether a similar dissociation could affect the vulnerability to VWM load.

CHAPTER 3 – GENERAL DISCUSSION

The main aim of the current thesis was to test the penetrability of distractor processing to top-down manipulations, and the stage at which task-relevant stimuli are rejected. In the present work we focused on the hypothesis that attentional capture by sudden changes and pleasant stimuli might be not entirely automatic. We addressed this issue by investigating the stage at which distractor processing might be affected by endogenous attention and the availability of VWM resources. In the first two studies we used two ERP indexes of exogenously driven attentional allocation (ACOP and VCOP). In the third study we analyzed the interference effects prompted by emotional stimuli, to index whether a distracting scene was selected over task-relevant elements even during VWM maintenance.

Overall, the present work shows that the spatial and emotional processing of sudden sounds and emotional scenes were completed, even if those stimuli were completely irrelevant for a task at hand, occurring at an unattended location and when the amount of visual working memory resources was reduced by an ongoing task. However, our findings indicate that the visual-cortical enhancement that is elicited after exogenous orienting to task-irrelevant stimuli is not automatic. For instance, in Experiments 1 and 3 we ensured that distractors were task-irrelevant by presenting them at an always unattended modality or location, respectively. Whereas emotional interference persisted even if scenes appeared outside the attentional window and even under high VWM load, the spatially-specific activation of visual cortex elicited by lateralized sounds was reduced when endogenous attention was directed to an opposite location. In Experiment 2 distractors could be somehow relevant for the task as they were presented in the attended modality and in the area of the task-relevant items. In this case, both endogenous spatial attention and VWM load were effective in filtering out the distractor. However, as will be discussed below, one possibility is that the relevance of the distractor to the task at hand may have encouraged the use of some active filtering strategies that were not necessary when the distractors were entirely unrelated to the task set. Notably, the present work provides just one little piece of the puzzle, that allow us just to make some speculative hypothesis. Further investigations are needed to draw stronger conclusions.

A possible explanation to the dissociation in the extent to which the ACOP and VCOP amplitudes were modulated by endogenous spatial attention relies in the different interference that might have been caused by acoustic and visual onsets. Whereas visual onsets were observed to have an impact on representations kept in visuospatial memory, evidence for interference effects of auditory distractors on stored visual information is limited. This difference might have encouraged the use of different filtering strategies. In a prior study (Van Der Stigchel, Merten, Meeter, & Theeuwes, 2007) observers had to memorize a target location for a short interval. During this interval, a task-irrelevant visual onset occurred in the same or in a different quadrant relative to the target position. The authors compared trials in which the distractor occurred to trials without an onset and observed that in trials in which the onset was presented the location kept in memory shifted toward the distractor, but only when it was close in space to the memory item. These findings suggested that the spatial memory representation and the task-irrelevant stimulus were represented on a common spatial map, and that this could explain the observed interference effects. Possibly, in the VCOP study, the match between the VWM contents and distractor modalities and locations required spatial filtering mechanisms to be activated. In contrast, sounds were entirely task-irrelevant, and so activating a spatial filter was not necessary to shield VWM representations against distraction. In such a case, the cost of engaging a strong spatial filter could exceed benefits (e.g., one could miss a significant warning signal while not enhancing performance). Ruthruff and Gaspelin (2018) proposed that only strong spatial filtering may prevent exogenous orienting to salient task-irrelevant stimuli, and that it occurs only when establishing a spatial filter is particularly convenient. One could speculate that a stronger spatial filter was engaged when distractor’s modality matched the one of the to-be remembered contents, and this could explain why the ACOP amplitude was only reduced when attention had previously been directed toward a different location by means of a central arrow cue, but the VCOP was eliminated.

Despite the described differences, we suggest that our findings might support the view that ACOP and VCOP represent two facets of the same biasing mechanism. (a) Acoustic and visual changes elicit a lateralized slow potential over the visual areas, even when they occur within an experimental context that is different from the classical exogenous cuing paradigm in which they were usually described; (b) this bias in the visual cortex is modulated by endogenous spatial attention. However, a great limitation of the present work is that it did not allow for a direct comparison of results across the two studies. Indeed, even though the same task was used to manipulate task demands, (a) ACOP and VCOP were measured in different groups of participants (also, in Experiment 1 participants were volunteers whereas in Experiment 2 they received course credit, and this could have had an impact on intrinsic motivation and task engagement); (b) several differences characterized the settings (e.g., different monitors and software versions for presentation). Future studies could involve direct comparison of top-down modulation of ACOP and VCOP using a within-subjects design in a more controlled context, in order to further investigate the link between these neural correlates of exogenous cuing. In addition to test similarities between the modulatory effects of endogenous spatial orienting on ACOP and VCOP, the impact of task set (Retsa et al., 2020) and spatial expectations (Matusz et al., 2016) on VCOP could be addressed.

As far as the role of VWM load is concerned, we observed that the spatial and emotional processing of salient stimuli that are entirely task-irrelevant is not conditioned to the availability of VWM resources. Previous research has shown that distractor interference is affected by VWM load (e.g., Konstantinou et al., 2014), but most of the evidence measured interference costs in terms of magnitude of congruency effects. Congruency effects reflects the ability to reduce the impact of stimulus-response associations elicited by “foils”. Thus, the attentional mechanism subtending congruency effects is driven by task-relevance rather than salience. De Fockert (2013) proposed that WM load effects are described by an inverted U-shaped function. Precisely, less salient events that are non-relevant (e.g., pictures of buildings) are ignored regardless of WM resource availability. Highly salient events (e.g., special classes of stimuli, like emotional ones) are processed even when WM is free to exert top-down control (i.e., attention is allocated to those stimuli reflexively). The processing of non-target stimuli at a mid-level of salience (e.g., color singletons or foils) is modulated by WM load. However, as foils and distractors might elicit different orienting responses in the attentional system, it would be controversial to discuss together the findings from experimental conditions that focus on traditional congruency effects and attentional capture. Indeed, whereas there is widespread evidence backing VWM’s role in task-relevance based guidance of attention, less support has been provided for a role of VWM in determining attentional capture based on stimulus salience. The role of VWM resources in supporting selective attention appears to apply mostly to conditions in which attentional control functions are involved, as operationalized with tasks such as the flanker task or the Stroop task, in which attentional orienting responses are elicited by items that exactly match the current templates, and prepotent responses must be stopped to respond correctly to a given trial.

A prior study on individual differences in WM capacity has suggested that WM may impact attentional control but not exogenous orienting of attention. Precisely, it has been shown that participants rated high and low in WM capacity differed in performance in a cognitive task that required attentional control, namely the antisaccade task (Unsworth, Schrock, & Engle, 2004). In the antisaccade task, participants must make a saccade toward (prosaccade) or away from (antisaccade) a flashing salient stimulus (Hallet, 1978; Heitz & Engle, 2007). At the beginning of the trial, participants fixate the center of the screen. After a variable interval, two boxes appear peripherally, and one of them begins to flash. Participants must gaze toward the box or away from it, depending on the specific condition. The antisaccade condition involves the inhibition of the prepotent response to orient in the direction of a salient stimulus and the endogenous orienting of attention in the opposite direction, accompanied by an overt gaze shift, whereas the prosaccade condition only involves overt attention toward the salient stimulus. It was observed that individuals with low and high WM spans oriented similarly towards the salient stimulus in the prosaccade condition, but low WM span participants made more errors in the antisaccade condition (Unsworth et al., 2004). The tendency to orient in the direction of the salient stimulus was stronger for individuals with low WM capacity, suggesting that attention control constraints were weaker when there were fewer WM resources available. In other words, mechanisms that are not determined by goal-driven control of attention, like stimulus-driven shifts towards salient visual cues, did not differ across participants as a function of WM capacity as attention was equally attracted by a flashing stimulus in both low and high capacity individuals.

The fact that saliency-based guidance of attention is not relying upon the WM system could reflect an adaptive strategy for the cognitive system, as failing to notice what happens in the environment could lead us to miss potential dangers or benefits. In the present work we observed that high VWM load had no impact on auditory spatial processing and emotional processing. Based on the perceptual load hypothesis of VWM load, one could expect stimuli that are not relevant to be filtered out early. Based on a recently proposed taxonomy, however, salient stimuli are actually relevant (Benoni & Ressler, 2020). It was proposed that “we are built to attend to salient items” (p. 2), as “salient items may be relevant based on phylogenetically implicit goals to perceive ecologically significant visual items, which make them essentially relevant, though they are not task-relevant”

(p. 2). From an ecological perspective, the selection of salient information is aimed at promoting the survival of the organism. For example, attentional capture in the present study was preserved for emotional scenes, but vanished when the scene was neutral, and the spatial processing of lateralized sounds, that represent particularly effective warning signals, was not affected by the amount of free VWM resources (it is of note, however, that our findings are based on the absence of significant effects, and so this represents just a speculation that will require further investigations). Another important process that was observed to be preserved even under high VWM load was the implicit learning of locations that are likely to contain a distractor (Gao & Theeuwes, 2020). All these mechanisms are crucial for successful organism's functioning, as attentional failures may have detrimental consequences in daily life (e.g., failing to notice that a fire alarm is ringing). For instance, it would be particularly adaptive for the exogenous attentional system to evolve to rapidly detect and recognize significant objects without relying on higher level processes linked to the working memory system. Please, note that we are admittedly cautious in discussing the results from Experiment 2 as: (a) it is possible that guidance was driven not only by stimulus salience but also by task-relevance, and that this had an impact on the stimulus' sensitivity to VWM load; (b) the asymmetry in perceptual demands between the two load conditions make it difficult to disentangle whether the effect of reduced distractor processing in the high VWM load condition is due to capacity consumption or structural interference.

In conclusion, our findings suggest that, even when mentally involved in a VWM task our system constantly analyzes the incoming information and allocates attentional resources to stimuli that are evaluated as ecologically relevant (i.e., sudden sounds and erotic scenes). However, the spatial processing of distractors, as reflected in the visual-cortical enhancement, is not entirely immune to top-down penetrations, as endogenous spatial attention might determine the extent to which attentional resources are allocated to task-irrelevant events. The modulatory effects might also depend upon the relevance of the distractor for the task set and the interference that it may exert on the task at hand. For example, when the distractor occurs in the same modality as the task, it is possible for some inhibitory process to be engaged (i.e., spatial filtering). Future studies are required to disentangle whether modulatory effects of VWM load are limited to distractor interference determined by the disruption of attentional control or if also purely stimulus-driven attentional capture relies on VWM resources. In this regard, it could be useful to systematically test the processing of several types of distractors, like threat-related (Maratos & Pessoa, 2019) or reward-related stimuli (Watson et al., 2019) during the storage of visual information.

REFERENCES

Adams, E. J., Nguyen, A. T., & Cowan, N. (2018). Theories of working memory: Differences in definition, degree of modularity, role of attention, and purpose. *Language, speech, and hearing services in schools*, 49(3), 340-355. https://doi.org/10.1044/2018_LSHSS-17-0114

Awh, E., Vogel, E. K., & Oh, S. H. (2006). Interactions between attention and working memory. *Neuroscience*, 139(1), 201-208. https://doi.org/10.1016/j.neuroscience.2005.08.023

Baddeley, A. (1996). The fractionation of working memory. *Proceedings of the National Academy of Sciences*, 93(24), 13468-13472. https://doi.org/10.1073/pnas.93.24.13468

Baddeley, A. D., & Hitch, G. (1974). Working memory. In Psychology of learning and motivation (Vol. 8, pp. 47-89). Academic press. https://doi.org/10.1016/S0079-7421(08)60452-1

Barley, B., Bauer, E. A., Wilson, K. A., & MacNamara, A. (2021). Working memory load reduces the electrocortical processing of positive pictures. *Cognitive, Affective, & Behavioral Neuroscience*, 21(2), 347-354. https://doi.org/10.3758/s13415-021-00875-z

Benoni, H. (2018). Can automaticity be verified utilizing a perceptual load manipulation?. *Psychonomic bulletin & review*, 25(6). DOI:10.3758/s13423-018-1444-7

Benoni, H., & Ressler, I. (2020). Dichotomy, Trichotomy, or a Spectrum: Time to Reconsider Attentional Guidance Terminology. *Frontiers in Psychology*, 11, 2243. https://doi.org/10.3389/fpsyg.2020.02243

Benoni, H., Zivony, A., & Tsal, Y. (2014). Attentional sets influence perceptual load effects, but not dilution effects. *Quarterly Journal of Experimental Psychology*, 67(4), 785-792. https://doi.org/10.1080/17470218.2013.830629

Berggren, N., & Eimer, M. (2018). Visual working memory load disrupts template-guided attentional selection during visual search. *Journal of cognitive neuroscience*, 30(12), 1902-1915. https://doi.org/10.1162/jocn_a_01324

Berti, S., & Schröger, E. (2003). Working memory controls involuntary attention switching: evidence from an auditory distraction paradigm. *European Journal of Neuroscience*, 17(5), 1119-1122. https://doi.org/10.1046/j.1460-9568.2003.02527.x

Bradley, M. M. (2009). Natural selective attention: Orienting and emotion. *Psychophysiology*, 46(1), 1-11. https://doi.org/10.1111/j.1469-8986.2008.00702.x

Broadbent, D. E. (1958).Perception and communication. New York:Oxford University Press

Buetti, S., & Lleras, A. (2016). Distractibility is a function of engagement, not task difficulty: Evidence from a new oculomotor capture paradigm. *Journal of Experimental Psychology: General*, 145(10), 1382. https://doi.org/10.1037/xge0000213

Calvo, M. G., Gutierrez-Garcia, A., & Del Líbano, M. (2015). Sensitivity to emotional scene content outside the focus of attention. *Acta psychologica*, 161, 36-44. https://doi.org/10.1016/j.actpsy.2015.08.002

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the acoustical society of America*, 25(5), 975-979. https://doi.org/10.1121/1.1907229

Chica, A. B., Bartolomeo, P., & Lupiáñez, J. (2013). Two cognitive and neural systems for endogenous and exogenous spatial attention. *Behavioural brain research*, 237, 107-123. https://doi.org/10.1016/j.bbr.2012.09.027

Codispoti, M., Ferrari, V., & Bradley, M. M. (2007). Repetition and event-related potentials: distinguishing early and late processes in affective picture perception. *Journal of Cognitive Neuroscience*, 19(4), 577-586. https://doi.org/10.1162/jocn.2007.19.4.577

Codispoti, M., Micucci, A., & De Cesarei, A. (2021). Time will tell: Object categorization and emotional engagement during processing of degraded natural scenes. *Psychophysiology*, 58(1), e13704. https://doi.org/10.1111/psyp.13704

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *The Behavioral and Brain Sciences*, 24, 87–114. https://doi.org/10.1017/S0140525X01003922

Cowan, N. (2017). The many faces of working memory and short-term storage. *Psychonomic bulletin & review,* 24(4), 1158-1170. https://doi.org/10.3758/s13423-016-1191-6

De Cesarei, A., Cavicchi, S., Micucci, A., & Codispoti, M. (2019). Categorization goals modulate the use of natural scene statistics. *Journal of cognitive neuroscience*, 31(1), 109-125. https://doi.org/10.1162/jocn_a_01333

De Cesarei, A., & Codispoti, M. (2008). Fuzzy picture processing: effects of size reduction and blurring on emotional processing. *Emotion*, 8(3), 352. https://doi.org/10.1037/1528-3542.8.3.352

De Cesarei, A., Loftus, G. R., Mastria, S., & Codispoti, M. (2017). Understanding natural scenes: Contributions of image statistics. *Neuroscience & Biobehavioral Reviews*, 74, 44-57. https://doi.org/10.1016/j.neubiorev.2017.01.012

De Fockert, J. W. (2013). Beyond perceptual load and dilution: a review of the role of working memory in selective attention. *Frontiers in psychology*, 4, 287. https://doi.org/10.3389/fpsyg.2013.00287

de Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science*, 291(5509), 1803-1806. DOI: 10.1126/science.1056496

de Fockert, J. W., & Theeuwes, J. (2012). Role of frontal cortex in attentional capture by singleton distractors. *Brain and cognition*, 80(3), 367-373. https://doi.org/10.1016/j.bandc.2012.07.006

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods*, 134(1), 9-21. https://doi.org/10.1016/j.jneumeth.2003.10.009

D'Esposito, M., & Postle, B. R. (2015). The cognitive neuroscience of working memory. *Annual review of psychology*, 66, 115-142. https://doi.org/10.1146/annurev-psych-010814-015031

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological review*, 70(1), 80. https://doi.org/10.1037/h0039515

Doherty, J. M., Belletier, C., Rhodes, S., Jaroslawska, A., Barrouillet, P., Camos, V., ... & Logie, R. H. (2019). Dual-task costs in working memory: An adversarial collaboration. *Journal of experimental psychology: learning, memory, and cognition,* 45(9), 1529. https://psycnet.apa.org/doi/10.1037/xlm0000761

Dowd, E. W., Kiyonaga, A., Beck, J. M., & Egner, T. (2015). Quality and accessibility of visual working memory during cognitive control of attentional guidance: A Bayesian model comparison approach. *Visual Cognition*, 23(3), 337-356. https://doi.org/10.1080/13506285.2014.1003631

Downing, P., & Dodds, C. (2004). Competition in visual working memory for control of search. *Visual Cognition,* 11(6), 689-703. https://doi.org/10.1080/13506280344000446

Drisdelle, B. L., Aubin, S., & Jolicoeur, P. (2017). Dealing with ocular artifacts on lateralized ERPs in studies of visual-spatial attention and memory: ICA correction versus epoch rejection. Psychophysiology, 54(1), 83-99. https://doi.org/10.1111/psyp.12675

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological review*, 87(3), 272. https://doi.org/10.1037/0033-295X.87.3.272

Eimer, M., & Kiss, M. (2008). Involuntary attentional capture is determined by task set: Evidence from event-related brain potentials. *Journal of cognitive neuroscience*, 20(8), 1423-1433. https://doi.org/10.1162/jocn.2008.20099

Eimer, M., & Kiss, M. (2010). Top-down search strategies determine attentional capture in visual search: Behavioral and electrophysiological evidence. *Attention, Perception, & Psychophysics,* 72(4), 951-962. https://doi.org/10.3758/APP.72.4.951

Engle, R. W. (2002). Working memory capacity as executive attention. *Current directions in psychological science*, 11(1), 19-23. https://doi.org/10.1111/1467-8721.00160

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of Learning and Motivation*, 44,145–199.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & psychophysics*, 16(1), 143-149. https://doi.org/10.3758/BF03203267

Eriksen, C. W., & James, J. D. S. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & psychophysics*, 40(4), 225-240. https://doi.org/10.3758/BF03211502

Feng, W., Störmer, V. S., Martinez, A., McDonald, J. J., & Hillyard, S. A. (2014). Sounds activate visual cortex and improve visual discrimination. *Journal of Neuroscience*, 34(29), 9817-9824. DOI: https://doi.org/10.1523/JNEUROSCI.4869-13.2014

Folk, C. L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human perception and performance*, 24(3), 847. https://doi.org/10.1037/0096-1523.24.3.847

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance,* 18(4), 1030–1044. https://doi.org/10.1037/0096-1523.18.4.1030

Forster, S., & Lavie, N. (2007). High perceptual load makes everybody equal. *Psychological science*, 18(5), 377-381. https://doi.org/10.1111/j.1467-9280.2007.01908.x

Forster, S., & Lavie, N. (2008). Failures to ignore entirely irrelevant distractors: the role of load. *Journal of Experimental Psychology: Applied*, 14(1), 73. doi:10.1037/1076-898X.14.1.73

Friedman, D., Cycowicz, Y. M., & Gaeta, H. (2001). The novelty P3: an event-related brain potential (ERP) sign of the brain's evaluation of novelty. *Neuroscience & Biobehavioral Reviews*, 25(4), 355-373. https://doi.org/10.1016/S0149-7634(01)00019-7

Gao, Y., & Theeuwes, J. (2020). Learning to suppress a distractor is not affected by working memory load. *Psychonomic bulletin & review*, 27(1), 96-104. https://doi.org/10.3758/s13423-019-01679-6

Gaspar, J. M., Christie, G. J., Prime, D. J., Jolicœur, P., & McDonald, J. J. (2016). Inability to suppress salient distractors predicts low visual working memory capacity. *Proceedings of the National Academy of Sciences,* 113(13), 3693-3698. https://doi.org/10.1073/pnas.1523471113

Gaspar, J. M., & McDonald, J. J. (2014). Suppression of salient objects prevents distraction in visual search. *Journal of neuroscience*, 34(16), 5658-5666. https://doi.org/10.1523/JNEUROSCI.4161-13.2014

Gaspelin, N., & Luck, S. J. (2018). The role of inhibition in avoiding distraction by salient stimuli. *Trends in cognitive sciences*, 22(1), 79-92. https://doi.org/10.1016/j.tics.2017.11.001

Gil-Gómez de Liaño, B., Stablum, F., & Umiltà, C. (2016). Can concurrent memory load reduce distraction? A replication study and beyond. *Journal of experimental psychology: general*, 145(1), e1- e12. https://doi.org/10.1037/xge0000131

Gil-Gómez de Liaño, B. G. G., Umiltà, C., Stablum, F., Tebaldi, F., & Cantagallo, A. (2010). Attentional distractor interference may be diminished by concurrent working memory load in normal participants and traumatic brain injury patients. *Brain and cognition*, 74(3), 298-305. https://doi.org/10.1016/j.bandc.2010.08.009

Golob, E. J., Winston, J., & Mock, J. R. (2017). Impact of spatial and verbal short-term memory load on auditory spatial attention gradients. *Frontiers in psychology,* 8, 2028. https://doi.org/10.3389/fpsyg.2017.02028

Guo, Y., Yao, N., Liu, Y., Gao, Z., Shen, M., & Shui, R. (2019). Visual working memory capacity load does not modulate distractor processing. *Journal of Vision,* 19(10), 103. http://dx.doi.org/10.1167/19.10.103

Gupta, R., Hur, Y. J., & Lavie, N. (2016). Distracted by pleasure: effects of positive versus negative valence on emotional capture under load. *Emotion*, 16(3), 328. http://dx.doi.org/10.1037/emo0000112

Hajcak, G., Weinberg, A., MacNamara, A., & Foti, D. (2012). ERPs and the study of emotion. In S. J. Luck & E. S. Kappenman (Eds.), The Oxford handbook of event-related potential components (pp. 441–472). Oxford University Press.

Hakim, N., Adam, K. C., Gunseli, E., Awh, E., & Vogel, E. K. (2019). Dissecting the neural focus of attention reveals distinct processes for spatial attention and object-based storage in visual working memory. *Psychological Science*, 30(4), 526-540. https://doi.org/10.1177/0956797619830384

Hakim, N., Feldmann-Wüstefeld, T., Awh, E., & Vogel, E. K. (2020). Perturbing neural representations of working memory with task-irrelevant interruption. *Journal of cognitive neuroscience*, 32(3), 558-569. https://doi.org/10.1162/jocn_a_01481

Hallett, P. E. (1978). Primary and secondary saccades to goals defined by instructions. *Vision research*, 18(10), 1279-1296. https://doi.org/10.1016/0042-6989(78)90218-3

Harrison, S. A., & Tong, F. (2009). Decoding reveals the contents of visual working memory in early visual areas. *Nature*, 458(7238), 632-635. https://doi.org/10.1038/nature07832

Heitz, R. P., & Engle, R. W. (2007). Focusing the spotlight: individual differences in visual attention control. *Journal of Experimental Psychology: General,* 136(2), 217. doi:10.1037/0096-3445.136.2.217

Henneman, R. H. (1952). Vision and audition as sensory channels for communication. *Quarterly Journal of Speech*, 38(2), 161-166. https://doi.org/10.1080/00335635209381758

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of cognitive neuroscience*, 18(4), 604-613. DOI: 10.1162/jocn.2006.18.4.604

Hillyard, S. A., Störmer, V. S., Feng, W., Martinez, A., & McDonald, J. J. (2016). Cross-modal orienting of visual attention. *Neuropsychologia*, 83, 170-178. https://doi.org/10.1016/j.neuropsychologia.2015.06.003

Hollingworth, A., Richard, A. M., & Luck, S. J. (2008). Understanding the function of visual short-term memory: transsaccadic memory, object correspondence, and gaze correction. *Journal of Experimental Psychology: General,* 137(1), 163. doi:10.1037/0096-3445.137.1.163

Holmes, A., Mogg, K., de Fockert, J., Nielsen, M. K., & Bradley, B. P. (2014). Electrophysiological evidence for greater attention to threat when cognitive control resources are depleted. *Cognitive, Affective, & Behavioral Neuroscience*, 14(2), 827-835. https://doi.org/10.3758/s13415-013-0212-4

Huynh Cong, S., & Kerzel, D. (2021). Allocation of resources in working memory: Theoretical and empirical implications for visual search. *Psychonomic Bulletin & Review*, 28(4), 1093–1111. https://doi.org/10.3758/s13423-021-01881-5

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision research*, 40(10-12), 1489-1506. https://doi.org/10.1016/S0042-6989(99)00163-7

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. *Attention and performance,* 187-203.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & psychophysics*, 43(4), 346-354. https://doi.org/10.3758/BF03208805

Junghöfer, M., Elbert, T., Tucker, D. M., & Rockstroh, B. (2000). Statistical control of artifacts in dense array EEG/MEG studies. *Psychophysiology*, 37(4), 523-532. doi:10.1111/1469-8986.3740523

Kahneman, D. (1984). Changing views of attention and automacy. *Varieties of attention*, 29-61.

Keefe, J. M., Pokta, E., & Störmer, V. S. (2021). Cross-modal orienting of exogenous attention results in visual-cortical facilitation, not suppression. *Scientific reports,* 11(1), 1-11. https://doi.org/10.1038/s41598-021-89654-x

Keil, A., & Ihssen, N. (2004). Identification facilitation for emotionally arousing verbs during the attentional blink. *Emotion*, 4(1), 23. https://doi.org/10.1037/1528-3542.4.1.23

Kiss, M., Jolicœur, P., Dell'Acqua, R., & Eimer, M. (2008). Attentional capture by visual singletons is mediated by top-down task set: New evidence from the N2pc component. *Psychophysiology*, 45(6), 1013-1024. https://doi.org/10.1111/j.1469-8986.2008.00700.x

Kyllonen, P. C., & Stephens, D. L. (1990). Cognitive abilities as determinants of success in acquiring logic skill. *Learning and individual differences*, 2(2), 129-160. https://doi.org/10.1016/1041-6080(90)90020-H

Kim, M. S., & Cave, K. R. (1999). Top-down and bottom-up attentional control: On the nature of interference from a salient distractor. *Perception & Psychophysics*, 61(6), 1009-1023. https://doi.org/10.3758/BF03207609

Kim, S. Y., Kim, M. S., & Chun, M. M. (2005). Concurrent working memory load can reduce distraction. *Proceedings of the National Academy of Sciences*, 102(45), 16524-16529. https://doi.org/10.1073/pnas.0505454102

Klein, R. M. (2000). Inhibition of return. *Trends in cognitive sciences*, 4(4), 138-147. https://doi.org/10.1016/S1364-6613(00)01452-2

Konstantinou, N., Beal, E., King, J. R., & Lavie, N. (2014). Working memory load and distraction: dissociable effects of visual maintenance and cognitive control. *Attention, Perception, & Psychophysics*, 76(7), 1985-1997. DOI 10.3758/s13414-014-0742-z

Konstantinou, N., & Lavie, N. (2013). Dissociable roles of different types of working memory load in visual detection. *Journal of Experimental Psychology: Human Perception and Performance*, 39(4), 919. http://dx.doi.org/10.1037/a0033037

Koshino, H., & Olid, P. (2015). Interactions between modality of working memory load and perceptual load in distractor processing. *The Journal of general psychology*, 142(3), 135-149. https://doi.org/10.1080/00221309.2015.1036830

Lachter, J., Forster, K. I., & Ruthruff, E. (2004). Forty-five years after Broadbent (1958): still no identification without attention. *Psychological review*, 111(4), 880. https://doi.org/10.1037/0033-295X.111.4.880

Lange, K., Kühn, S., & Filevich, E. (2015). " Just Another Tool for Online Studies"(JATOS): An easy solution for setup and management of web servers supporting online studies. *PloS one*, 10(6), e0130834. https://doi.org/10.1371/journal.pone.0130834

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human perception and performance*, 21(3), 451. http://dx.doi.org/10.1037/0096-1523.21.3.451

Lavie, N. (2010). Attention, distraction, and cognitive control under load. *Current directions in psychological science,* 19(3), 143-148. https://doi.org/10.1177/0963721410370295

Lavie, N., Beck, D. M., & Konstantinou, N. (2014). Blinded by the load: attention, awareness and the role of perceptual load. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1641), 20130205. https://doi.org/10.1098/rstb.2013.0205

Lavie, N., & Cox, S. (1997). On the efficiency of visual selective attention: Efficient visual search leads to inefficient distractor rejection. *Psychological Science*, 8(5), 395-396. https://doi.org/10.1111/j.1467-9280.1997.tb00432.x

Lavie, N., & De Fockert, J. W. (2003). Contrasting effects of sensory limits and capacity limits in visual selective attention. *Perception & Psychophysics,* 65(2), 202-212. https://doi.org/10.3758/BF03194795

Lavie, N., & De Fockert, J. (2005). The role of working memory in attentional capture. *Psychonomic bulletin & review*, 12(4), 669-674. https://doi.org/10.3758/BF03196756

Lavie, N., Hirst, A., De Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of experimental psychology: General,* 133(3), 339. doi:10.1037/0096-3445.133.3.339

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & psychophysics*, 56(2), 183-197. https://doi.org/10.3758/BF03213897

Leblanc, É., Prime, D. J., & Jolicoeur, P. (2008). Tracking the location of visuospatial attention in a contingent capture paradigm. *Journal of cognitive neuroscience*, 20(4), 657-671. doi: 10.1162/jocn.2008.20051.

Lee, H., & Jeong, S. K. (2020). Separating the effects of visual working memory load and attentional zoom on selective attention. *Journal of Experimental Psychology: Human Perception and Performance,* 46(5), 502. https://doi.org/10.1037/xhp0000730

Lee, H., & Yi, D. J. (2018). Visual short-term memory load does not enhance attentional selection. *Journal of Vision*, 18(10), 1181-1181. https://doi.org/10.1167/18.10.1181

Li, Q., Joo, S. J., Yeatman, J. D., & Reinecke, K. (2020). Controlling for participants' viewing distance in large-scale, psychophysical online experiments using a virtual chinrest. *Scientific reports*, 10(1), 1-11. https://doi.org/10.1038/s41598-019-57204-1

Lin, P. H., & Luck, S. J. (2012). Proactive interference does not meaningfully distort visual working memory capacity estimates in the canonical change detection task. *Frontiers in psychology*, 3, 42. https://doi.org/10.3389/fpsyg.2012.00042

Lin, S. H., & Yeh, Y. Y. (2014). Domain-specific control of selective attention. *PLoS One*, 9(5), e98260. https://doi.org/10.1371/journal.pone.0098260

Lleras, A., Buetti, S., & Mordkoff, J. T. (2013). When do the effects of distractors provide a measure of distractibility?. In *Psychology of Learning and Motivation* (Vol. 59, pp. 261-315). Academic Press. https://doi.org/10.1016/B978-0-12-407187-2.00007-1

Lleras, A., Chu, H., & Buetti, S. (2017). Can we "apply" the findings of Forster and Lavie (2008)? On the generalizability of attentional capture effects under varying levels of perceptual load. *Journal of Experimental Psychology: Applied*, 23(2), 158. https://doi.org/10.1037/xap0000116

Logie, R. H., & Pearson, D. G. (1997). The inner eye and the inner scribe of visuo-spatial working memory: Evidence from developmental fractionation. *European Journal of cognitive psychology,* 9(3), 241-257. https://doi.org/10.1080/713752559

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Frontiers in human neuroscience*, 8, 213. https://doi.org/10.3389/fnhum.2014.00213

Luck, S. J., Gaspelin, N., Folk, C. L., Remington, R. W., & Theeuwes, J. (2021). Progress toward resolving the attentional capture debate. *Visual Cognition*, 29(1), 1-21. https://doi.org/10.1080/13506285.2020.1848949

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, 390(6657), 279-281. https://doi.org/10.1038/36846

Luck, S. J., & Vogel, E. K. (2013). Visual working memory capacity: from psychophysics and neurobiology to individual differences. *Trends in cognitive sciences,* 17(8), 391-400. https://doi.org/10.1016/j.tics.2013.06.006

Luria, R., Balaban, H., Awh, E., & Vogel, E. K. (2016). The contralateral delay activity as a neural measure of visual working memory. *Neuroscience & Biobehavioral Reviews*, 62, 100-108. https://doi.org/10.1016/j.neubiorev.2016.01.003

MacNamara, A., Ferri, J., & Hajcak, G. (2011). Working memory load reduces the late positive potential and this effect is attenuated with increasing anxiety. *Cognitive, Affective, & Behavioral Neuroscience*, 11(3), 321-331. https://doi.org/10.3758/s13415-011-0036-z

Magnussen, S., & Greenlee, M. W. (1992). Retention and disruption of motion information in visual short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18(1), 151. https://doi.org/10.1037/0278-7393.18.1.151

Maratos, F. A., & Pessoa, L. (2019). What drives prioritized visual processing? A motivational relevance account. *Progress in brain research*, 247, 111-148. https://doi.org/10.1016/bs.pbr.2019.03.028

Marciano, H., & Yeshurun, Y. (2011). The effects of perceptual load in central and peripheral regions of the visual field. *Visual Cognition*, 19(3), 367-391. https://doi.org/10.1080/13506285.2010.537711

Marteniuk, R. G. (1986). Information processes in movement learning: Capacity and structural interference effects. *Journal of Motor Behavior*, 18(1), 55-75. https://doi.org/10.1080/00222895.1986.10735370

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior research methods*, 44(2), 314-324. https://doi.org/10.3758/s13428-011-0168-7

Matusz, P. J., Retsa, C., & Murray, M. M. (2016). The context-contingent nature of cross-modal activations of the visual cortex. *Neuroimage*, 125, 996-1004. https://doi.org/10.1016/j.neuroimage.2015.11.016

Mazza, V., Turatto, M., Umiltà, C., & Eimer, M. (2007). Attentional selection and identification of visual objects are reflected by distinct electrophysiological responses. *Experimental Brain Research,* 181(3), 531-536. https://doi.org/10.1007/s00221-007-1002-4

McDonald, J. J., Störmer, V. S., Martinez, A., Feng, W., & Hillyard, S. A. (2013). Salient sounds activate human visual cortex automatically. *Journal of Neuroscience*, 33(21), 9194-9201. DOI: https://doi.org/10.1523/JNEUROSCI.5902-12.2013

McDonald, J. J., Teder-Sälejärvi, W. A., Di Russo, F., & Hillyard, S. A. (2005). Neural basis of auditory-induced shifts in visual time-order perception. *Nature neuroscience*, 8(9), 1197-1202. https://doi.org/10.1038/nn1512

McDonald, J. J., Teder-Sälejärvi, W. A., & Hillyard, S. A. (2000). Involuntary orienting to sound improves visual perception. *Nature*, 407(6806), 906-908. https://doi.org/10.1038/35038085

McDonald, J. J., Whitman, J. C., Störmer, V. S., Hillyard, S. A., & Mangun, G. R. (2013). Involuntary cross-modal spatial attention influences visual perception. *Cognitive electrophysiology of attention: signals of the mind*. Academic, Oxford, 82-94. http://dx.doi.org/10.1016/B978-0-12-398451-7.00007-5

Micucci, A., Ferrari, V., De Cesarei, A., & Codispoti, M. (2020). Contextual modulation of emotional distraction: attentional capture and motivational significance. *Journal of cognitive neuroscience,* 32(4), 621-633. https://doi.org/10.1162/jocn_a_01505

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological review*, 63(2), 81. https://doi.org/10.1037/h0043158

Miller, J. (1987). Priming is not necessary for selective-attention failures: Semantic effects of unattended, unprimed letters. *Perception & Psychophysics,* 41(5), 419-434. https://doi.org/10.3758/BF03203035

Moors, A., & De Houwer, J. (2006). Automaticity: a theoretical and conceptual analysis. *Psychological bulletin*, 132(2), 297. https://doi.org/10.1037/0033-2909.132.2.297

Moray N. (1959) Attention in dichotic listening: Affective cues and the influence of instructions, *Quarterly Journal of Experimental Psychology*, 11:1, 56-60. 10.1080/17470215908416289

Müller, H. J., & Rabbitt, P. M. (1989). Reflexive and voluntary orienting of visual attention: time course of activation and resistance to interruption. *Journal of Experimental psychology: Human perception and performance*, 15(2), 315. https://doi.org/10.1037/0096-1523.15.2.315

Murphy, G., Groeger, J. A., & Greene, C. M. (2016). Twenty years of load theory—Where are we now, and where should we go next?. *Psychonomic bulletin & review*, 23(5), 1316-1340. https://doi.org/10.3758/s13423-015-0982-5

Oberauer, K. (2019). Working memory and attention–A conceptual analysis and review. *Journal of cognition,* 2(1), 36. http://doi.org/10.5334/joc.58

O'Brien, F., & Cousineau, D. (2014). Representing error bars in within-subject designs in typical software packages. *The quantitative methods for psychology*, 10(1), 56-67.

Olivers, C. N., Meijer, F., & Theeuwes, J. (2006). Feature-based memory-driven attentional capture: visual working memory content affects visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, 32(5), 1243. https://doi.org/10.1037/0096-1523.32.5.1243

Olivers, C. N., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in cognitive sciences*, 15(7), 327-334. https://doi.org/10.1016/j.tics.2011.05.004

Otten, L. J., Alain, C., & Picton, T. W. (2000). Effects of visual attentional load on auditory processing. *Neuroreport*, 11(4), 875-880.

Pashler, H. (1988). Familiarity and visual change detection. *Perception & psychophysics,* 44(4), 369-378. https://doi.org/10.3758/BF03210419

Pasternak, T., & Greenlee, M. W. (2005). Working memory in primate sensory systems. *Nature Reviews Neuroscience,* 6(2), 97-107. https://doi.org/10.1038/nrn1603

Pecchinenda, A., & Heil, M. (2007). Role of working memory load on selective attention to affectively valent information. *European Journal of Cognitive Psychology*, 19(6), 898-909. https://doi.org/10.1080/09541440601095388

Pessoa, L. (2008). On the relationship between emotion and cognition. *Nature reviews neuroscience,* 9(2), 148-158. https://doi.org/10.1038/nrn2317

Peyk, P., De Cesarei, A., & Junghöfer, M. (2011). ElectroMagnetoEncephalography software: overview and integration with other EEG/MEG toolboxes. *Computational intelligence and neuroscience*, 2011. https://doi.org/10.1155/2011/861705

Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics*, 16(2), 283-290. https://doi.org/10.3758/BF03203943

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, 32(1), 3-25. https://doi.org/10.1080/00335558008248231

Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience*, 139(1), 23-38. https://doi.org/10.1016/j.neuroscience.2005.06.005

Rees, G., Frith, C. D., & Lavie, N. (1997). Modulating irrelevant motion perception by varying attentional load in an unrelated task. *Science*, 278(5343), 1616-1619. DOI: 10.1126/science.278.5343.1616

Retsa, C., Matusz, P. J., Schnupp, J. W., & Murray, M. M. (2020). Selective attention to sound features mediates cross-modal activation of visual cortices. *Neuropsychologia*, 144, 107498. https://doi.org/10.1016/j.neuropsychologia.2020.107498

Roper, Z. J., & Vecera, S. P. (2014). Visual short-term memory load strengthens selective attention. *Psychonomic bulletin & review*, 21(2), 549-556. https://doi.org/10.3758/s13423-013-0503-3

Rouder, J. N., Morey, R. D., Morey, C. C., & Cowan, N. (2011). How to measure working memory capacity in the change detection paradigm. *Psychonomic bulletin & review,* 18(2), 324-330. https://doi.org/10.3758/s13423-011-0055-3

Ruthruff, E., & Gaspelin, N. (2018). Immunity to attentional capture at ignored locations. Attention, *Perception, & Psychophysics*, 80(2), 325-336. https://doi.org/10.3758/s13414-017-1440-4

SanMiguel, I., Corral, M. J., & Escera, C. (2008). When loading working memory reduces distraction: behavioral and electrophysiological evidence from an auditory-visual distraction paradigm. *Journal of Cognitive Neuroscience*, 20(7), 1131-1145. doi: 10.1162/jocn.2008.20078

SanMiguel, I., Linden, D., & Escera, C. (2010). Attention capture by novel sounds: Distraction versus facilitation. European Journal of Cognitive Psychology, 22(4), 481-515. https://doi.org/10.1080/09541440902930994

Santangelo, V., Olivetti Belardinelli, M., & Spence, C. (2007). The suppression of reflexive visual and auditory orienting when attention is otherwise engaged. *Journal of Experimental Psychology: Human Perception and Performance*, 33(1), 137. https://doi.org/10.1037/0096-1523.33.1.137

Sauter, M., Draschkow, D., & Mack, W. (2020). Building, hosting and recruiting: A brief introduction to running behavioral experiments online. Brain sciences, 10(4), 251. https://doi.org/10.3390/brainsci10040251

Sawaki, R., & Luck, S. J. (2010). Capture versus suppression of attention by salient singletons: Electrophysiological evidence for an automatic attend-to-me signal. *Attention, Perception, & Psychophysics*, 72(6), 1455-1470. https://doi.org/10.3758/APP.72.6.1455

Sawaki, R., & Luck, S. J. (2011). Active suppression of distractors that match the contents of visual working memory. *Visual cognition*, 19(7), 956-972. https://doi.org/10.1080/13506285.2011.603709

Schlögl, A., Keinrath, C., Zimmermann, D., Scherer, R., Leeb, R., & Pfurtscheller, G. (2007). A fully automated correction method of EOG artifacts in EEG recordings. *Clinical neurophysiology*, 118(1), 98-104. https://doi.org/10.1016/j.clinph.2006.09.003

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review*, 84(1), 1–66. https://doi.org/10.1037/0033-295X.84.1.1

Schweizer, S., Satpute, A. B., Atzil, S., Field, A. P., Hitchcock, C., Black, M., ... & Dalgleish, T. (2019). The impact of affective information on working memory: A pair of meta-analytic reviews of behavioral and neuroimaging evidence. *Psychological Bulletin*, 145(6), 566. http://dx.doi.org/10.1037/bul0000193

Serences, J. T., Ester, E. F., Vogel, E. K., & Awh, E. (2009). Stimulus-specific delay activity in human primary visual cortex. *Psychological science*, 20(2), 207-214. https://doi.org/10.1111/j.1467-9280.2009.02276.x

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological review*, 84(2), 127. https://doi.org/10.1037/0033-295X.84.2.127

Simon, S. S., Tusch, E. S., Holcomb, P. J., & Daffner, K. R. (2016). Increasing working memory load reduces processing of cross-modal task-irrelevant stimuli even after controlling for task difficulty and executive capacity. *Frontiers in human neuroscience*, 10, 380. https://doi.org/10.3389/fnhum.2016.00380

Sokolov, E. N. (1963). Perception and the conditioned reflex. New York: Macmillan.

Souza, A. S., & Oberauer, K. (2016). In search of the focus of attention in working memory: 13 years of the retro-cue effect. *Attention, Perception, & Psychophysics*, 78(7), 1839-1860. https://doi.org/10.3758/s13414-016-1108-5

Spence, C. (2010). Crossmodal spatial attention. Annals of the New York Academy of Sciences, 1191(1), 182-200. https://doi.org/10.1111/j.1749-6632.2010.05440.x

Spence, C. J., & Driver, J. (1994). Covert spatial orienting in audition: Exogenous and endogenous mechanisms. *Journal of experimental psychology: Human perception and performance*, 20(3), 555. doi:10.1037/0096-1523.20.3.555

Spence, C., & Driver, J. (1997). Audiovisual links in exogenous covert spatial orienting. *Perception & psychophysics*, 59(1), 1-22. https://doi.org/10.3758/BF03206843

Spence, C., & McDonald, J. (2004). The Cross-Modal Consequences of the Exogenous Spatial Orienting of Attention. In G. A. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 3–25). MIT Press.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs: General and Applied,* 74(11), 1–28. https://doi.org/10.1037/h0093759

Spinks, J. A., Zhang, J. X., Fox, P. T., Gao, J. H., & Tan, L. H. (2004). More workload on the central executive of working memory, less attention capture by novel visual distractors: evidence from an fMRI study. *Neuroimage*, 23(2), 517-524. https://doi.org/10.1016/j.neuroimage.2004.06.025

Störmer, V. S., Feng, W., Martinez, A., McDonald, J. J., & Hillyard, S. A. (2016). Salient, irrelevant sounds reflexively induce alpha rhythm desynchronization in parallel with slow potential shifts in visual cortex. Journal of cognitive neuroscience, 28(3), 433-445. https://doi.org/10.1162/jocn_a_00915

Störmer, V. S., Green, J. J., & McDonald, J. J. (2009). Tracking the voluntary control of auditory spatial attention with event-related brain potentials. *Psychophysiology*, 46(2), 357-366. https://doi.org/10.1111/j.1469-8986.2008.00778.x

Störmer, V. S., McDonald, J. J., & Hillyard, S. A. (2009). Cross-modal cueing of attention alters appearance and early cortical processing of visual stimuli. Proceedings of the National Academy of Sciences, 106(52), 22456-22461. https://doi.org/10.1073/pnas.0907573106

Störmer, V. S., McDonald, J. J., & Hillyard, S. A. (2019). Involuntary orienting of attention to sight or sound relies on similar neural biasing mechanisms in early visual processing. *Neuropsychologia*, 132, 107122. https://doi.org/10.1016/j.neuropsychologia.2019.107122

Szychowska, M., & Wiens, S. (2020). Visual load does not decrease the auditory steady-state response to 40-Hz amplitude-modulated tones. *Psychophysiology*, 57(12), e13689. https://doi.org/10.1111/psyp.13689

Tavares, T. P., Logie, K., & Mitchell, D. G. (2016). Opposing effects of perceptual versus working memory load on emotional distraction. *Experimental brain research*, 234(10), 2945-2956. https://doi.org/10.1007/s00221-016-4697-2

Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception & psychophysics*, 49(1), 83-90. https://doi.org/10.3758/BF03211619

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & psychophysics*, 51(6), 599-606. https://doi.org/10.3758/BF03211656

Theeuwes, J. (2010). Top–down and bottom–up control of visual selection. *Acta psychologica*, 135(2), 77-99. https://doi.org/10.1016/j.actpsy.2010.02.006

Theeuwes, J. (2018). Visual Selection: Usually Fast and Automatic; Seldom Slow and Volitional. *Journal of Cognition*, 1(1), 29. http://doi.org/10.5334/joc.13

Theeuwes, J., Kramer, A. F., & Belopolsky, A. V. (2004). Attentional set interacts with perceptual load in visual search. *Psychonomic Bulletin & Review*, 11(4), 697-702. https://doi.org/10.3758/BF03196622

Thom, N., Knight, J., Dishman, R., Sabatinelli, D., Johnson, D. C., & Clementz, B. (2014). Emotional scenes elicit more pronounced self-reported emotional experience and greater EPN and LPP modulation when compared to emotional faces. *Cognitive, Affective, & Behavioral Neuroscience,* 14(2), 849-860. https://doi.org/10.3758/s13415-013-0225-z

Thompson, G. L. (2006). An SPSS implementation of the nonrecursive outlier deletion procedure with shifting z score criterion (Van Selst & Jolicoeur, 1994). *Behavior Research Methods*, 38(2), 344-352. https://doi.org/10.3758/BRM.38.2.344

Thompson, G. C., & Masterton, R. B. (1978). Brain stem auditory pathways involved in reflexive head orientation to sound. *Journal of neurophysiology*, 41(5), 1183-1202.

Treisman, A. M., & Riley, J. G. (1969). Is selective attention selective perception or selective response? A further test. *Journal of Experimental Psychology*, 79(1p1), 27. https://doi.org/10.1037/h0026890

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory & Language,* 28,127-154. https://doi.org/10.1016/0749-596X(89)90040-5

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working memory capacity and the antisaccade task: individual differences in voluntary saccade control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30(6), 1302. https://doi.org/10.1037/0278-7393.30.6.1302

Van der Stigchel, S., Merten, H., Meeter, M., & Theeuwes, J. (2007). The effects of a task-irrelevant visual event on spatial working memory. *Psychonomic Bulletin & Review*, 14(6), 1066-1071. https://doi.org/10.3758/BF03193092

Van Selst, M., & Jolicoeur, P. (1994). A solution to the effect of sample size on outlier elimination. *The Quarterly Journal of Experimental Psychology Section A*, 47(3), 631-650. https://doi.org/10.1080/14640749408401131

Vogel, E. K., & Machizawa, M. G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature*, 428(6984), 748-751. https://doi.org/10.1038/nature02447

von Bastian, C. C., Blais, C., Brewer, G., Gyurkovics, M., Hedge, C., Kałamała, P., ... & Wiemers, E. (2020). Advancing the understanding of individual differences in attentional control: Theoretical, methodological, and analytical considerations. https://doi.org/10.31234/osf.io/x3b9k

Wang, B., van Driel, J., Ort, E., & Theeuwes, J. (2019). Anticipatory distractor suppression elicited by statistical regularities in visual search. *Journal of cognitive neuroscience*, 31(10), 1535-1548. https://doi.org/10.1162/jocn_a_01433

Watson, P., Pearson, D., Chow, M., Theeuwes, J., Wiers, R. W., Most, S. B., & Le Pelley, M. E. (2019). Capture and control: Working memory modulates attentional capture by reward-related stimuli. *Psychological science*, 30(8), 1174-1185. https://doi.org/10.1177/0956797619855964

Weaver, M. D., van Zoest, W., & Hickey, C. (2017). A temporal dependency account of attentional inhibition in oculomotor control. *Neuroimage*, 147, 880-894. https://doi.org/10.1016/j.neuroimage.2016.11.004

Wheeler, M. E., & Treisman, A. M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General,* 131(1), 48. https://doi.org/10.1037/0096-3445.131.1.48

Wolfe, J. M. (2020). Forty years after feature integration theory: An introduction to the special issue in honor of the contributions of Anne Treisman. *Attention, Perception, & Psychophysics*, 82(1), 1-6. https://doi.org/10.3758/s13414-019-01966-3

Woodman, G. F., Luck, S. J., & Schall, J. D. (2007). The role of working memory representations in the control of attention. *Cerebral cortex*, 17(suppl_1), i118-i124. https://doi.org/10.1093/cercor/bhm065

Wöstmann, M., Störmer, V. S., Obleser, J., Addleman, D. A., Andersen, S., Gaspelin, N., ... & Theeuwes, J. (2021). Ten simple rules to study distractor suppression. *PsyArXiv*, DOI: 10.31234/osf.io/vu2k3.

Xu, Y. (2017). Reevaluating the sensory account of visual working memory storage. *Trends in Cognitive Sciences,* 21(10), 794-815. https://doi.org/10.1016/j.tics.2017.06.013

Yang, P., Wang, M., Jin, Z., & Li, L. (2015). Visual short-term memory load modulates the early attention and perception of task-irrelevant emotional faces. *Frontiers in Human Neuroscience,* 9, 490. https://doi.org/10.3389/fnhum.2015.00490

Yao, N., Guo, Y., Liu, Y., Shen, M., & Gao, Z. (2020). Visual working-memory capacity load does not modulate distractor processing. *Attention, Perception, & Psychophysics*, 82(7), 3291-3313. https://doi.org/10.3758/s13414-020-01991-7

Yi, D. J., Woodman, G. F., Widders, D., Marois, R., & Chun, M. M. (2004). Neural fate of ignored stimuli: dissociable effects of perceptual and working memory load. *Nature neuroscience*, 7(9), 992-996. https://doi.org/10.1038/nn1294

Yoon, J. H., Curtis, C. E., & D'Esposito, M. (2006). Differential effects of distraction during working memory on delay-period activity in the prefrontal cortex and the visual association cortex. *Neuroimage*, 29(4), 1117-1126. https://doi.org/10.1016/j.neuroimage.2005.08.024

Zanto, T. P., Liu, H., Pan, P., & Gazzaley, A. (2020). Temporal attention is not affected by working memory load. *Cortex*, 130, 351-361. https://doi.org/10.1016/j.cortex.2020.06.008

Zhang, W., & Luck, S. J. (2008). Discrete fixed-resolution representations in visual working memory. *Nature*, 453(7192), 233-235. https://doi.org/10.1038/nature06860

Zhang, W., & Luck, S. J. (2015). Opposite effects of capacity load and resolution load on distractor processing. *Journal of Experimental Psychology: Human Perception and Performance*, 41(1), 22. https://doi.org/10.1037/xhp0000013