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"THE IMPACT OF EMOTIONAL STRESSORS ON DISTRACTOR FILTERING"

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Coordinator: Prof. Gianluigi Zanusso

Signature ___________________________

Tutor: Prof. Leonardo Chelazzi

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Co-Tutor: Dr. Chiara della Libera

Signature ___________________________

Doctoral Student: Dr. Alessia Patacca

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Abstract

Human beings constantly deal with an enormous amount of information that cannot be processed at once. Given the limited cognitive resources available for the processing of incoming information, visual selective attention has the role to differentiate between competing stimuli in order to facilitate the processing of stimuli that are relevant for adaptive behaviours.

From an evolutionary perspective, stimuli with emotional content, in particular those signalling danger or threat, are very powerful in attracting and holding attention even if they are task-irrelevant. Moreover, emotional stimuli get higher processing priority compared with other competing stimuli and their access to further processing and conscious perception is thought to be automatic, at least when sufficient cognitive resources are available. Therefore, avoiding emotional stimuli, especially those with negative content, requires a conspicuous amount of resources that, if engaged for a prolonged period of time in a highly demanding cognitive task, they can undergo depletion, and eventually lead to the mental fatigue phenomenon. We propose that the amount of resources specifically dedicated to selective attention are also limited, and that they can be depleted specifically, and possibly independently, from the resources available for other cognitive mechanisms.

This work was planned in order to directly explore this possibility, assuming that the crucial resources necessary to overcome the impact of irrelevant emotional distractors are also involved in attentional processing, and – more specifically – in the filtering of distracting visual information. We expected that by heavily engaging these inhibitory mechanisms, providing conditions of heavy and persistent distraction, we would observe phenomena suggesting that they were being depleted during the course of the experimental session (i.e. one-hour session).

In a series of visual search experiments, young adult participants had to discriminate a target stimulus, while ignoring a task-irrelevant distractor that could be present in a portion of trials. According to the aim of our research, in order to increase, on the one hand, the attentional load and, on the other, the need

to filter out distracting information, task-irrelevant stimuli with emotional content were introduced prior to each visual search trial. I then measured performance to evaluate the overall impact of emotional stimuli, revealing that while the onset of all emotional stimuli affected attentional deployment in the subsequent trial, such impact was different according to the valence of the stimuli involved. Analysing the efficiency of distractor filtering processes over the experimental session, I observed changes in performance suggesting that the attentional resources specifically involved during the inhibition of distractors in the visual search task could indeed be depleted. By this new approach, in this series of studies I offered new evidence relative to the depletion of cognitive resources specific associated with selective attention. I demonstrated that these domain-specific resources can be depleted in a relatively short period of time (i.e., one-hour session). Moreover, I highlighted how emotional activation can either enhance or impair cognitive performance depending on the emotional valence of the stimuli involved, with negative emotions leading to detrimental effects and positive emotions leading to restorative effects on cognitive resources. I also provided evidence on the fact that under condition of high load on attentional processing, the active engagement of top-down behavioural control may limit, or even abolish, the detrimental effects of negative emotional stimuli.

Contents

Chapter 1

Visual Selective Attention

1.1 Visual selective attention

In everyday life, we are constantly exposed to a huge amount of sensory information derived from external and internal sources. Nevertheless, at any given moment only a small part of the incoming information can reach awareness and play a role in guiding behaviour, because our cognitive system has limited processing resources. At all times the available stimuli compete with each other in order to gain access for further processing. In this respect selective attention is the gateway to cognition: it allows us to focus on relevant sensory information while filtering out the irrelevant stimuli. Specifically, visual selective attention operates such filtering with respect to stimuli in the visual domain (Chelazzi et al., 2011; Desimone & Duncan, 1995; Reynolds & Chelazzi, 2004).

But how exactly does visual selective attention "decide" which stimuli should be selected, and which should be ignored?

1.2 Bottom-up and top-down: two attentional control mechanisms

William James (1980) first delineated two varieties of attention over a century ago (James, 1980): one being passive, involuntary and reflexive and the other one active and voluntary.

Nowadays, we refer to these as *bottom-up* and *top-down* or the less metaphorical *stimulus-driven* or *goal-driven*. Bottom-up (or exogenous) attention is referred to an externally induced process in which attentional control is driven by highly noticeable featural properties of stimuli that are present in the environment (e.g., Jonides, 1981; Jonides & Yantis, 1988; Theeuwes, 1991a, 1992, 1994, 2004; Yantis, 1993; Yantis & Jonides, 1984).

Traditionally, bottom-up selection is associated with stimuli whose salience is such that they "pop-out" from their background, because their basic features (e.g., colour, luminance or orientation) are very different from those of other surrounding objects. Typically, the processing of pop-out stimuli can occur "in parallel", without the need of examining every element in the scene which contains them (Duncan & Humphreys, 1989; Treisman & Gelade, 1980). This evidence fuelled the theoretical approach adopted by the Feature Integration Theory, which claimed that the apparently effortless attentional processing of pop-out stimuli relies on the fact that simple stimulus features such as colour, luminance and orientation are represented in different areas at the early stage of cortical visual processing, and therefore can be processed in parallel, independently from one another (Treisman & Gelade, 1980).

Under certain circumstances, stimuli whose features render them capable of triggering bottom-up attentional control may act as strong distractors, if they are not relevant for the participants' current goals, drawing attention away from other stimuli which are instead task-relevant. When objects or events gain priority in being processed independently of the volitional goal of the observer one refers to this as *attentional capture* effect (Theeuwes, 1992).

Recent research has shown that bottom-up selection (and attentional capture) can also occur for stimuli that, while bearing no salient low-level features, have a high intrinsic value, for instance because in the past their selection has been repeatedly associated with rewarding events (Anderson et al., 2011). Moreover, attentional capture has also been observed for stimuli that are maintained in working memory, even if completely irrelevant for the task at hand (Pinto et al., 2005; Olivers et al., 2006).

In contrast, top-down (or endogenous) attention is referred to an internally induced process, driven by active volitional selection of stimuli that are relevant with respect to a person's goals, and also implies that, in order to deal with the relevant information, attention must be withheld from other irrelevant stimuli even if they are salient (Egeth & Yantis, 1997; Connor et al, 2004; Corbetta e Shulman, 2002; Itti & Koch, 2001; Carrasco, 2011; Ansorge & Heumann, 2003; Bacon & Egeth, 1994; Folk & Remington, 1999; Folk, Remington, & Johnston, 1992, 1993; Folk, Remington, & Wright, 1994; Gibson & Kelsey, 1998; Lamy, Leber, & Egeth, 2004).

Posner (1980) firstly described top-down selection using an experimental procedure called the endogenous cueing paradigm. Participants in each trial received a cue suggesting them the likely location of the forthcoming target, which required a behavioural response. The cue consisted of a centrally presented arrow that pointed at the location of the upcoming target. Faster reaction times and fewer errors were reported when the target appeared at the cued location compared to uncued ones. This implied on the one hand that attention had been allocated to the cued spatial location, facilitating the processing of targets appearing therein; on the other that, when a target appeared where it was not expected, attention needed to be shifted from the cued location towards the target (Posner, 1980).

Over the years, a very interesting debate has been going on regarding the way in which bottom-up and top-down selection processes may interact in controlling attentional deployment. More specifically, the interest has been directed in understanding whether the two may truly be independent forms of attentional control, or whether one may somehow subserve the other, within a hierarchical organization of cognitive processing (Corbetta & Shulman, 2002; Theeuwes & Belopolsky, 2010; Theeuwes & Godijn, 2001; Raushenberger, 2003; Burnham, 2007). The dichotomy between top-down and bottom-up forms of attentional control has been extensively studied by means of experimental paradigms leading to attentional capture.

1.3 Attentional capture paradigms

One of the first authors to investigate systematically attentional control mechanisms was Jonides (1981). In his study, he revealed how the allocation of visual selective attention in space could be efficiently manipulated by means of a *spatial precuing paradigm*, which involves the presentation of a cue prior to the appearance of a target (Fig.1). The target appeared equally often at each location, independently of the cue's location and therefore the cue and the target locations coincided at chance level. Jonides observed that when the target appeared at the cued location reaction times were faster, thus suggesting that the cue indeed captured attention, despite being non-relevant nor predictive of target location (Jonides, 1981).

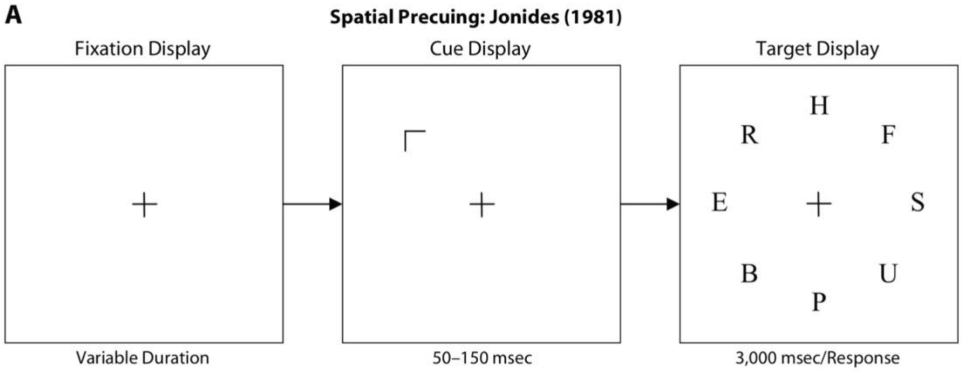


Figure 1. Sample trial sequence from the Spatial Precuing paradigm.

Another paradigm commonly adopted to investigate attentional capture is the *irrelevant singleton paradigm*, where subjects are asked to respond to a target stimulus presented within an array of stimuli, one of which appears abruptly in a proportion of trials (Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; J. T. Todd & Van Gelder, 1979; S. Todd & Kramer, 1994; Treisman & Gelade, 1980; Yantis & Egeth, 1999; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984). Within the stimulus set, one item is a singleton, in that it bears properties that are unique with respect to the others, but this distinguishing feature is task-irrelevant, in that it is randomly associated with target or non-target objects. For instance, Yantis and Jonides (1984) (Fig.2) asked participants to search for a prespecified target letter (E) among several non-targets (H, S, and R) and to report whether the target was present or not. The set size was varying, trial by trial. The search display was initially defined by placeholders in the shape of a digital eight (Fig. 2). Later, parts of the placeholders were erased so that a letter was created in each of the positions previously occupied by the placeholders (non-onset letters). In some trials a new letter appeared abruptly (the cue), in a previously unoccupied location. In a random fashion, this new letter could be the target (*target-onset* condition), or a non-target letter (*target-nononset* condition). The authors found that in the target onset condition reaction times were not modulated by the set size, suggesting that the abruptly appearing letter captured attention, facilitating performance when it was the target to be reported. Conversely, in the target absent condition and target-nononset condition, the attentional capture effect – due to the presence of the irrelevant onset – increased as a function of set size, reflecting that attention was effectively drawn towards the irrelevant onset, which added to the number of items to be explored prior to providing a task response (Yantis and Jonides, 1984).

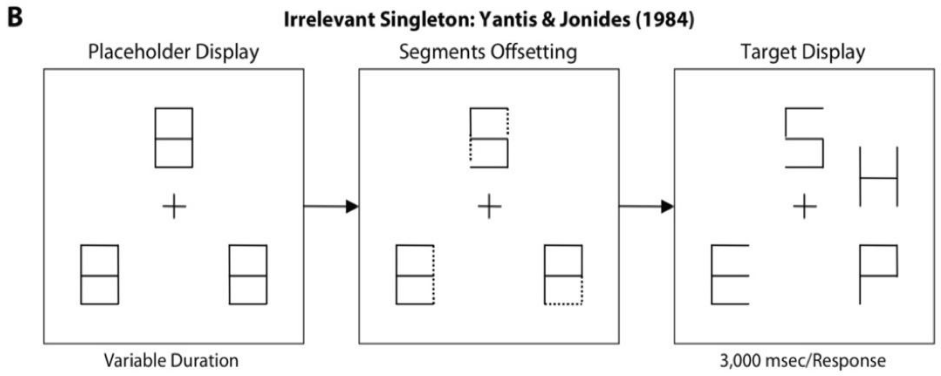


Figure 2. Sample trial sequence from the Irrelevant Singleton paradigm.

Later on, the irrelevant singleton paradigm has been revisited by Theeuwes (1991a, 1991b, 1992, 2004), who proposed the *distractor interference paradigm*. This task was very similar to the previous one because the attentional cue and target appeared simultaneously, within a set of visual stimuli, but it differs from it because cue and target locations never coincided. In this task (Fig.3), participants were looking for an item, the cue that was a singleton with respect to the remaining objects on the screen (i.e., a green circle among green diamonds) and had to identify the orientation of a small bar presented inside of it. In the *distractor-absent* condition, all of the items were in the same colour (i.e., green); whereas, in the *distractor-present* condition, one of the non-relevant items was red, and was therefore a colour singleton, acting as a salient distractor. It was found that reaction times were slower in the distractor-present condition compared to the distractor-absent condition, reflecting that upon stimulus display presentation attention shifted to the distractor first, slowing reaction times to the target (Theeuwes 1991a; Theeuwes, 1991b; Theeuwes, 1992; Theeuwes, 2004).

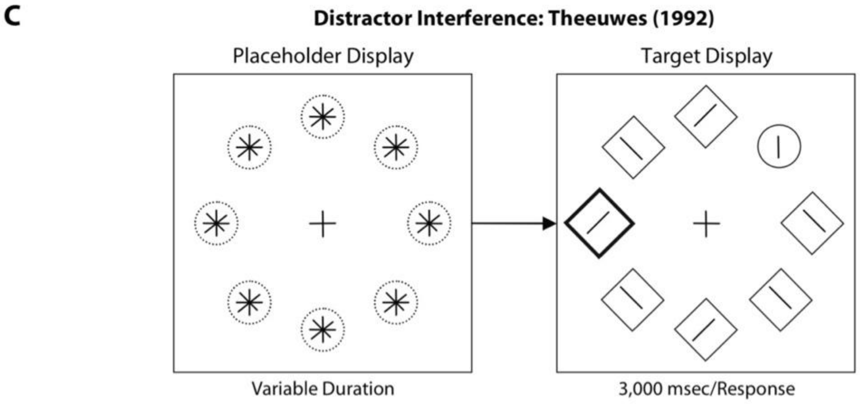


Figure 3. Sample trial sequence from the Distractor Interference paradigm.

A different methodological perspective was provided by *the contingent cueing paradigm*, based on Folk et al.'s (1992) *contingent involuntary orienting hypothesis*, in which involuntary attentional capture can only be observed, and therefore is contingent to, a salient event bearing features that are shared with the target, and therefore task-relevant. It is known for example, that when an object is maintained in memory, it will capture attention more easily with respect to others, even if it is completely irrelevant for the task at hand (Pinto et al., 2005; Olivers, 2006). According to this theory therefore, observers place target-relevant feature information into attentional sets which are maintained in memory and affect attentional deployment in order to locate the target (Folk, Leber & Egeth, 2002; Folk & Remington, 1996, 1998, 1999; Folk et al., 1993; Folk et al., 1994). In their typical experiments (Fig.4), the target (X or = symbols) was a single red item among three white items. The red item should, therefore, be included in the attentional set, because it was relevant for locating the target. Prior to target onset, sets of four dots (one red and three white) were presented around each potential target location. According to Folk. et al.'s hypothesis, attention should have been captured by the red dot cue, because of the relevance assigned to the "red" colour. Indeed, they observed costs in performance when the red dots appeared around a location which would not be occupied by the target, reflecting the effect of attentional capture associated with the red dots. Moreover, by comparing these results to those emerged in a condition in which the target was an onset singleton (an X or =, appearing alone), they did not observe any attentional capture effect, presumably because in this case the target-defining property was the “abrupt onset” feature, rather than “red color” (Folk, Remington, & Johnston, 1992).

Contingent Cueing Paradigm: Folk et al (1992)

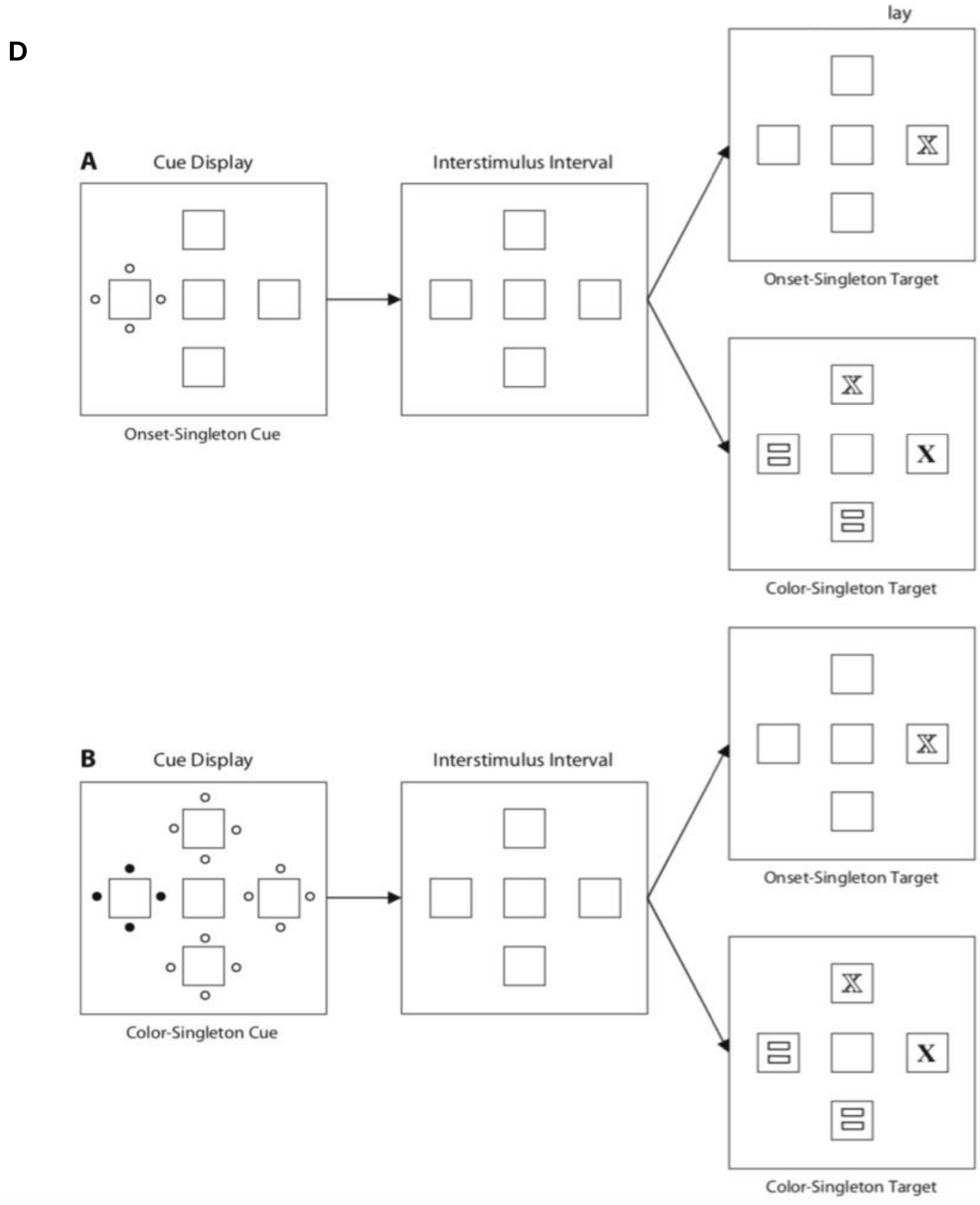


Figure 4. Sample trial sequence from the Contingent Cued paradigm.

1.4 The attentional capture effect

The top-down guidance of visual selective attention is thought to imply two main processes, both intrinsically involved in information filtering operations: the enhanced processing of task-relevant stimuli (target facilitation) and the suppression of the competing information (distractor suppression). During target facilitation, the contribution of visual selective attention is reflected in faster reaction times and fewer error rates in responses to task-relevant information, which can be easily observed for instance when targets appear at locations which are currently at the focus of attention, with respect to when they appear elsewhere. When selection is made more difficult, especially because the target must be discriminated against a number of other objects, stimulus filtering operations rely heavily also on distractor suppression mechanisms, which suppress the processing of non-relevant and potentially distracting information and is then followed by the selection of relevant items. The involvement of distractor suppression mechanisms typically depends on the degree of interference determined by the non-target objects available, and is heavily taxed when non-target stimuli are capable of attentional capture, and hence act as powerful distractors. In these cases in fact the presence of salient but irrelevant stimuli causes an automatic shift of attention that can disrupt performance at the ongoing task, giving rise to the well-known *attentional capture* effect (AC), which leads to slower reaction times and greater error rates (Theeuwes, 1992; Folk, Remington, & Johnston, 1992; Jonides, 1981; Jonides & Yantis, 1988; Posner, 1980; Posner & Cohen, 1984; Posner, Snyder, & Davidson, 1980; Theeuwes, 1992, 1994, 2004; J. T. Todd & Van Gelder, 1979; Yantis & Egeth, 1999; Yantis & Jonides, 1984). Thus, AC can be considered as a measure of distractibility determined by the automatic engagement on bottom-up mechanisms of attentional control (Tommasi et al., 2015).

In general, distracting information, even if task-irrelevant, exerts a negative effect on attentional processing, which has been assessed in several behavioural (Forster & Lavie, 2008; Lavie & Cox, 1997; Theeuwes & Burger, 1998; Theeuwes & Godijin, 2002), neuropsychological (Reynold, Chelazzi & Desimone, 1999), and neuroimaging (Kastner, De Weerd, Desimone & Ungerleider, 1998) studies. However, whether distractor suppression should be acknowledged as the result of mechanisms that are independent from those involved in target selection is still a matter of debate. For instance, according to the biased competition account of visual selective attention, the allocation of attentional resources depends on a mechanism which acts in the visual scene by biasing, on the basis of top-down instructions, the competitive interactions arising among multiple stimuli and eventually enhancing the relevant one (Desimone, 1998; Desimone & Duncan, 1995; Reddy et al., 2009). The suppression of distractor information is viewed as the direct consequence of such biasing operations, which would therefore be responsible for both, facilitatory and suppressive aspects of visual selective attention, with no need to foresee the involvement of mechanisms specifically responsible for an active filtering of distractors. However, other studies provided ample evidence suggesting that attentional mechanisms specifically involved in distractor filtering may indeed exist, and play a crucial role in cognition. Many of these studies moved from the observation that task performance can improve dramatically when, although dealing with a context in which target information is surrounded by distracting stimuli, distractors are expected, and therefore it is possible to engage a strategic form of cognitive control which would allow to suppress the processing of distractors and reduce the relative behavioural costs. Hence, two neural mechanisms, within the brain systems supporting selective attention, are thought to be mainly involved in dealing with distracting information. First, selective attention can cope with distractors by trying to either suppress them in the same moment they occur (Awh, Matsukura & Serences, 2003) or by temporarily enhancing resources assigned to the main task (Carrasco, Penepecitalgar, & Eckstein, 2000; Yeshurun & Carrasco, 1998), or both. In these cases, the strategies adopted to allow distractor filtering are considered as “reactive”, triggered on a moment-to-moment basis by the processing needs posed by the current situation. Alternatively, when distraction can be predicted, it might be possible to adopt a “preventive”, or “proactive” strategy. Specifically, the selective attention might constantly engage part of the processing resources available, specifically for the suppression of potential distractors. Accordingly, Marini and colleagues (2012) demonstrated that, in potentially distracting contexts, a filtering mechanism is engaged in order to cope with the forthcoming distractors. This mechanism relies on resource-demanding processes and therefore while improving performance in trials in which distractors are present, it also causes a substantial – but generalized – performance cost, when the expected distraction is absent (Marini, Chelazzi, & Maravita, 2012). However, when distraction is expected to occur only in a relative minority of the total trials, it might be disadvantageous to engage the sustained activation of filtering mechanisms, since they weigh heavily on processing resources. Indeed, when distraction is relatively unlikely, it might be more convenient to rely on mechanisms which filter distractors based on a reactive, rather than strategic, processes (Morishima, Okuda, & Sakai, 2010; Marini et al. 2012). In line with these hypotheses, it has been demonstrated that the manipulation of distractor probability leads to different levels of interference. Specifically, the lower the probability of distractors presence, and hence the more likely is the adoption of a "reactive" strategy, the higher the inference they engendered, and vice versa (Geyer, Muller and Krummenacher, 2008). Furthermore, by analysing task performance as a function of distractor presence across consecutive trials, Geyer and colleagues (2008) revealed that the interference associated with a distractor in the current trial was reduced if the preceding trial also contained a distractor, suggesting that such facilitation might be due to the repeated activation of on-line, reactive, distractor suppression mechanisms across trials (Geyer et al., 2008). Overall therefore, contextual circumstances play an important role in modulating attentional settings, crucially depending on whether and how distraction is likely to appear.

Interestingly, many studies have recently shown that the attentional capture effect can be modulated by a number of stimulus properties, which are not linked to their basic salience. For instance, bottom-up selection can be triggered by the emotional value of the stimuli, or the experience gained when interacting with them in the past. A growing body of literature has recently revealed that reward (or punishment) can exert a strong influence on attention. In particular, specific stimuli and spatial locations can acquire increased attentional priority when their selection has been systematically associated with reward (Della Libera & Chelazzi, 2006; 2009; Kristjansson, Sigurjonsdottir, & Driver, 2010; Della Libera et al., 2011; Anderson et al., 2011a; 2011b; for a review, see Chelazzi et al., 2013; Anderson, 2016). As well, it has been highlighted over the years that emotional stimuli exert an important role in controlling attentional deployment, especially the unpleasant ones (B. P. Bradley et al., 1997; Hansen & Hansen, 1988). Indeed, studies have suggested that stimuli with an emotional value are powerful attractors and attention retainers, being able to capture attention automatically, thus disrupting performance to an ongoing task (Hodsoll et al., 2011; Yiend, 2010).

Chapter 2

Emotion and Attention

2.1 Emotional stimuli and attention: Two different points of view

As explained above, selective attention addresses cognitive resources to behaviourally relevant stimuli and events, thereby enhancing the processing of attended relative to unattended information (Desimone & Duncan, 1995; Treue, 2003).

Several studies have demonstrated that emotional stimuli are very powerful in attracting attention and can interfere with the overall deployment of attentional resources. In fact, emotionally salient stimuli can capture attention, disrupting the ongoing task performance, even if they are task-irrelevant, and therefore should be ignored (Hodsoll et al., 2011; Yiend, 2010). A large number of studies suggested that these stimuli gain priority in order to be processed over other objects in the environment because they are very relevant for survival, from an evolutionary perspective (Ohman et al., 2001; Vuilleumier et al., 2001; Anderson et al., 2003; Phelps et al., 2006). In fact, a bias towards the prioritization of emotional stimuli is always likely to occur when there is competition among stimuli to access the limited attentional resources of an individual. This bias has an adaptive function since it allows humans to efficiently detect these events and to rapidly prepare adaptive reactions (Pourtois et al., 2013). This topic represented the main focus of interest of many researchers over the recent years, both in neuroscience (Vuilleumier, 2005) and psychology (Van Bockstaele et al., 2014; Yiend, 2010), and it has been investigated through different experimental paradigms. Hindi Attar and colleagues (2010) used pleasant, unpleasant and neutral pictures selected from the International Affective Picture System (Lang et al., 1999). The images were presented in intact or phase-scrambled form and were superimposed by a flickering display in which dots were moving randomly. On every trial subjects had to attend to the moving dots and to detect short intervals of coherent motion while ignoring the picture in the background. This task allowed to record steady-state visual evoked potential (SSVEPs) in the EEG signal, in order to obtain a continuous neurophysiological measure of the degree to which attentional resources were allocated to the task. Results showed that pleasant and unpleasant pictures exerted a greater interference on task-related processing compared to neutral ones, reflected in a significant decrease in SSVEP amplitudes and target detection rates (Hindi Attar et al., 2010).

Having established that emotional stimuli capture attention, a very long debate has been carried on to establish whether their processing is automatic or whether instead, besides being prioritized, it depends on the basis of the available attentional resources (Pessoa et al., 2002; Pessoa, 2005; Vuilleumier et al., 2001; Vuilleumier, 2005). According to the traditional view, emotional stimuli produce interference on the main task because they gain priority access to central processing resources and, moreover, this prioritization occurs in an automatic way and is not affected by limits in the availability of attentional resources (Morris et al. 1999; Ohman et al., 2001; Vuilleumier et al., 2001). Consistent with this view, neuroimaging studies have reported that emotional stimuli, with respect to other non-emotional stimuli, can be detected and processed with greater efficacy, or automatically, giving rise to increased activations in the amygdala, a main brain structure associated with emotional processing (Aggleton, 1992; Le Doux, 2000; Adolphs et al., 1995; Young et al. 1995; Breiter et al., 1996b; LaBar et al. 1998; Morris et al., 1996; Morris et al., 1998a; Morris et al. 1998b; Whalen et al., 1998b). Accordingly, studies showed that the experimental manipulation of attentional resources does not modulate amygdala responsiveness, thus supporting the idea that emotional stimuli are processed automatically (Vuilleumier et al. 2001; Dolan & Vuilleumier, 2003). Whalen and colleagues, using brain imaging evidence demonstrated that facial stimuli with emotional expressions can also be processed without awareness (Whalen et al., 1998). Using event-related functional magnetic resonance imaging (fMRI), Vuilleumier and colleagues (2001) showed an activation of the amygdala for fearful facial expressions that was not modulated by attention. Participants performed an attentionally demanding matching task for pairs of stimuli which could be houses, either identical or different, and faces, either fearful or neutral. Task relevant and irrelevant stimuli were shown in each trial, and participants were required to attend either houses or faces and to make same/different judgment. Results showed an increased activity in the amygdala during the exposure of fearful faces, both when they were relevant and when they were irrelevant for the main task. Moreover, also in line with these results, reaction times to houses were slower when fearful faces were displayed concurrently as distractors, suggesting that emotional stimuli drained cognitive resources from the processing of concurrent task-relevant information (Vuilleumier et al., 2001). Anderson and colleagues (2003) also confirmed that the response of amygdala to fearful faces was found irrespectively of whether they were relevant or not with respect to the task. Specifically, participants were shown stimuli which consisted of superimposed pictures of a face (fearful, disgusted or neutral) and of a location (a building or an image of exteriors). In each trial faces were shown to participants in two task conditions: in the attended condition they had to discriminate the gender of the face, and in the unattended condition they had to discriminate the building/exteriors type of location. (Anderson et al., 2003). A number of studies suggested that such automatic processing of emotional visual stimuli may rely on a subcortical pathway, including amygdala, pulvinar, and superior colliculus, which seems to be implied in particular during the processing of stimuli with a threatening value (Linke et al., 1999; Morris et al., 2001).

Thus, based on this traditional view, it is possible to hypothesise that emotional stimuli may be processed by parallel networks that allow on the one hand the automatic and unconscious pre-attentional processing of these stimuli, and on the other a conscious type of processing, which affects the allocation of cognitive resources (Adolphs, 2004; Anderson & Phelps, 2001; LeDoux, 2000; Pourtois et al., 2004; Pourtois et al., 2006; Vuilleumier et al., 2004).

Studies have shown that at any given moment attentional resources are limited. Based on these observations, Lavie (2005) claimed that the degree to which irrelevant information is processed (and therefore is allowed also to interfere with other ongoing tasks) depends on the perceptual load imposed by the processing of the relevant ones, because under normal circumstances the attentional resources available will be always used up (Lavie, 2005). In fact, it is only after having allocated resources to the relevant stimuli for the current task that any remaining resources will be allocated to the irrelevant ones. As a consequence, a high perceptual load situation that requires the full engagement of resources for the processing of task-relevant stimuli would leave no spare resources for the irrelevant ones. Whereas, in a low perceptual load situation, all the available resources would be allowed to – involuntarily – become engaged by task-irrelevant distractors. This hypothesis has been tested by manipulating the attentional load of the main task, in order to spare different levels of brain resources to process irrelevant emotional stimuli. Thus, according to the traditional view, if emotional stimuli are processed in an automatic way, then they should be processed anyways, even if no resources were available, being fully required by the main task.

Based on Lavie's theory, Pessoa and colleagues (2002) criticized the previous studies which suggested that the processing of emotional stimuli is automatic and unaffected by their task-relevance, because the tasks used were not demanding enough to deplete attentional processing resources. In their study these authors used a more demanding task, in which fearful, happy or neutral faces were displayed at fixation, while oriented bars were shown in the left and right periphery. Participants received two conditions: in the attended condition, they had to indicate whether the face was male or female, while, on the other hand, in the unattended condition they had to indicate whether the orientations of the lateral bars were similar or not. The attentional focus hence was always the comparison between trials with emotional and non-emotional stimuli. Results showed that in the attended condition fearful faces evoked a greater response in the network associated with emotional processing, including the amygdala. Instead, in the unattended condition this activation was not found. Therefore, they concluded that emotional information could be processed only when the task at hand is cognitively low-demanding and hence does not require the full engagement of attentional resources (Pessoa et al., 2002).

Singer and colleagues (2007), in line with the suggestion of Pessoa et al. (2002), confirmed that the processing of emotional stimuli is dependent on attention, or, better, they need the availability of sufficient attentional resources in order to be processed. In their experiments, they found that despite the display of emotional pictures that were always task-irrelevant, pictures with negative content interfered more with task performance compared to neutral ones; however, this interference occurred only when there were sufficient attentional resources available for picture processing. Hence, they suggested that although the processing of emotional stimuli can be automatic, it also requires attentional resources (Singer et al., 2007).

Nonetheless, the way in which emotional stimuli are processed remains still unclear, since the evidence supporting this debate between the competing views is based on manipulations that were carried out in different studies, with different tasks and experimental requirements. In fact, studies supporting the traditional view were mostly characterized by tasks that could be viewed as not challenging enough (Anderson et al., 2003; Luo et al.,2010; Vuilleumier et al., 2001), and studies from the competing view could have used emotional stimuli which were not powerful enough for being automatically prioritized (Mitchell et al., 2007; Pessoa, 2005; Pessoa et al., 2002; Pourtois et al., 2006; Silvert et al., 2007).

2.2 The negative attention bias

As described above, emotional stimuli are powerful in attracting and retaining attention (Hodsoll et al., 2011; Yend, 2010; Anderson & Phelps, 2001; Keil & Ihssen, 2004; Ohman et al., 2001; Zeelenberg et al., 2006) and their attentional salience has been investigated by means of different experimental paradigms, tapping visual selective attention from different perspectives (the emotional Stroop task; Phaf & Khan, 2007; dot-probe task, Mogg et al., 1997; visual search task, Ohman et al., 2001; spatial cueing task Fox et al., 2002). Besides demonstrating that emotional stimuli are powerful in attracting attention, studies have also suggested that there might be a substantial difference in the processing associated with stimuli with a different emotional valence (Hindi Attar et al., 2010, Eastwood et al., 2001; Fox, 2002; Ohman et al., 2001). For instance, when subjects are asked to judge the degree of emotional valence of images that are equally arousing, negative stimuli receive more extreme values than positive ones (Ito et al., 1998).

According to this assumption, many studies found that negative emotional stimuli are processed more thoroughly than neutral picture stimuli, especially under conditions of high cognitive load (Kern et al., 2005). Helton and Russell (2011) for instance demonstrated that task-unrelated negative emotional stimuli compared to neutral ones impaired significantly target detection in a vigilance task (Helton and Russell, 2011). Pictures with a negative emotional valence are also remembered with greater accuracy with respect to stimuli with a neutral content (Helton et al., 2009; Kern et al., 2005). Interestingly, it has consistently been demonstrated that negative emotional stimuli exert a greater impact on information processing not only with respect to neutral information, but also compared to stimuli with a positive valence (Baumeister et al., 2001; Cacioppo and Gardner, 1999; Taylor, 1991). Following this evidence, studies have tried to investigate the nature of this differential effect of negative and positive emotional stimuli, in order to reveal whether differences can be found at specific levels of cognitive information processing. For instance, it is plausible that the bias towards negative information may occur at processing levels that precede the explicit evaluation of the stimulus. Important evidence in this respect was provided by Ito and colleagues (1998). In their experiment, participants were exposed to positive, negative and neutral pictures while their event-related brain potentials (ERPs) were recorded from their EEG signal. The researchers highlighted a bias in affective processing towards negative pictures emerging very early, presumably reflecting a stage of initial stimulus categorization into valence classes (Ito et al., 1998). Specifically, the differentiation between positive and negative stimuli occurred extremely rapidly, in less than 120 ms (Smith et al., 2003). The bias toward negative information has been documented in the literature by a large body of studies. Researchers hypothesise that it may have an adaptive function, in fact it is thought to be responsible for helping humans to safely explore the surrounding environment while avoiding harmful situations (Cacioppo et al., 1997; Cacioppo, 1999). Moreover, it is manifested through different response systems, such as those related to cognitive, emotional and social behaviour (Cacioppo et al., 1999; Mogg et al., 1998; Mogg et al., 2000; Peeters et al., 1990; Taylor, 1991). One of the first studies carried out in order to understand the attentional bias towards negative stimuli was conducted by Hansen and Hansen (1988). In their experiment participants were shown arrays of happy faces, comprising a single angry face, or arrays of angry faces, with a single happy face, and they demonstrated that participants were faster in finding the angry face among the happy faces than vice-versa. These results were taken as evidence reflecting the automaticity with which negative emotional stimuli capture attention (Hansen and Hansen, 1988). Later on, other studies have suggested however that this attention bias might not be associated with negative stimuli in general, but only with threatening faces (Ohman et al., 2001).

However, several studies have demonstrated not only that negative emotional events elicit more rapid and prominent responses than neutral or positive ones (Carretié et al., 2000; Dijksterhuis et al., 2003; Armony & Dolan, 2002; Erthal, et al., 2005; Pessoa, et al., 2005; Anderson, et al., 2003; Mogg & Bradley, 1998; Mogg et al., 2000; Baumeister, et al., 2001; Cacioppo & Gardner, 1999; Taylor, 1991), but that in order to be detected they need less stimulus input (Carretié et al., 2000). One possible reason illustrated by Cacioppo and colleagues (1999) is that negative emotional information summons mental and behavioural adjustment, whereas positive or neutral information indicates that "we are safe" and therefore, does not necessarily modify our approach toward a stimulus. Instead, positive emotional information might encourage perseverance with our initial behaviour (Cacioppo et al., 1999).

2.3 Positive emotional stimuli and attention

After having focused on studying negative emotional stimuli, more recent research has been directed also towards the investigation of attention biases towards positive emotional stimuli. In this respect, many studies have investigated such biases towards stimuli that have acquired a “positive” value because they are, or have been in the past, systematically associated with rewarding consequences. So, for instances, attentional biases have been found for drug-related stimuli in the context of substance abuse, or for food in patients with eating disorders (Brignell et al., 2009, Field & Cox., 2008; Franken, 2003; Field et al., 2009). In the general population attentional biases for positively valued stimuli appears more clearly towards images depicting babies, erotically attractive adults, money, self-related information and food stimuli (Lang et al., 2009; Pool et al., 2016). Interestingly, attentional biases towards positive stimuli are found more easily when the emotional stimuli consist of pictures, rather than words (Pool, et al., 2016; Pishyar et al., 2007). Besides describing their general effects on attentional processing, more recently, researchers have also discovered that positive stimuli portraying natural scenes seem to have a restorative effect on cognitive processing, suggesting that the display of such material may be beneficial for improving the working of cognitive mechanisms (Berman, et al., 2008; Berto, 2005; Cimprich & Ronis, 2003; Faber, Taylor, Kuo, & Sullivan, 2002; Hartig et al., 2003; Tennessen & Cimprich, 1995). On the basis of these observations, Kaplan (1995) formulated a new approach for restoring cognitive mechanisms and named it the *attention restoration theory* (ART; Kaplan, 1995, 2001). Directed attention was identified as the mechanism that is restored by the interaction with either nature or natural scenes since natural environments are innately fascinating and evoke a type of effortless attention, or fascination, that allows directed attention to rest and restore (Kaplan, 1995). Tennessen and Cimprich (1995) showed that students who rated their attentional functioning as more effective were those who had in the university dormitory natural views from their windows (Tennessen and Cimprich, 1995). On the other hand, Berto (2005) showed how, after performing a demanding sustained attention test, the cognitive functions of participants could be restored also by exposing them to pictures with natural scenes. In her experiment participants were shown photographs of restorative environments, nonrestorative environments or geometrical patterns. In agreement with Kaplan's theory, only subjects exposed to the restorative environments improved their performance on the final attention test (Berto, 2005). Up to now, a large body of studies demonstrated that interactions with natural environments are more restorative than those with urban environments (Herzog, Black, Fountaine, & Knotts, 1997; Herzog, Chen, & Primeau, 2002; Kaplan, 1995;Kaplan R., 2001; Purcell, Peron, & Berto, 2001;Tennessen & Cimprich, 1995; Ulrich, 1984; Ulrich et al., 1991) and improve attention and memory (Berto, 2005; Cimprich, 1992, 1993; Cimprich & Ronis, 2003; Faber et al., 2002; Hartig et al., 2003; Ottosson & Grahn, 2002; Tennessen & Cimprich, 1995).

In conclusion, emotional stimuli, even if task-irrelevant, exert a great influence on cognitive control and in particular on attentional resources. Although the specific effects associated with emotional stimuli with negative or positive valence may differ, it is generally acknowledged that given their high intrinsic salience, from an evolutionary perspective, emotional stimuli attract and retain attention very powerfully. Hence, when they are non-relevant and need to be ignored, attentional resources will be recruited in order to allow for their suppression. As a consequence, the resources available for the attentional processing of other concurrent stimuli will be depleted.

Chapter 3

A brief history of limited resources

3.1 Why limited resources?

In everyday life, the human brain continuously computes representations of the sensory world, however, it does not have sufficient processing capacity in order to analyse in detail all the information it receives (Tsotsos J.K. et al, 1995, Marois and Ivanoff, 2005; Dux et al., 2006).

Therefore, attentional mechanisms must select, at a relatively early stage of information processing, the most important aspects of the environment while filtering out the less relevant sensory inputs (James, 1980; Chun, et al. 2011; Moran J. & Desimone R., 1985). Under certain circumstances, this targeted selection, driven by attentional mechanisms, can give rise to costs in responses to behaviourally relevant events, due to the fact that different types of information compete for access to a processing bottleneck.

These limitations are mostly evident in dual-task settings (Welford A.T., 1952; Welford A.T., 1980; Pashler et al., 1994). In fact, when people perform two tasks at the same time, large costs are usually likely to occur, reflected by larger processing time and error rate in both tasks when they are performed concurrently as compared to when they are performed in isolation, in single-task situations. One of the possible reasons thought to explain why these processing costs emerge in situations in which people do two things at once is that central attentional resources are limited (Welford A.T., 1952; Welford A.T., 1980; Pashler et al., 1994). These limitations have been described in terms of a depletion of a pool of limited attentional resources that takes place under high attentional demands (Kahneman, 1973; Wickens, 2002; Lavie, 2005).

3.2 The bottleneck model over the years

The idea that selective attention subserves a processing bottleneck within the cognitive system was first proposed by Broadbent (1958), becoming one of the earliest and most influential models of selective attention, the *Bottleneck model* (Fig.1A). Using a dichotic listening task, he investigated how much people remembered from a speech to which they did not pay attention. Participants, while hearing two streams of auditory information through a headphone set, had to attend to one source (e.g., the sounds coming from the left) and disregard the other (Cherry, 1953). He showed that, when they were asked to report the information heard through the unattended channel, participants were only able to report changes in its physical properties, such as a drastic change in pitch or tone, and they were completely unable to recall the topic or anything related to the semantic contents. According to Broadbent's filter theory, perceptual processing is defined by two different stages. The first stage is an automatic process which is affected by the physical properties of the stimuli and does not require attention. The abstract properties of the stimuli would be processed by the second stage which, hypothesized as a serial mechanism, allows only one stream of input at a time. Broadbent theorized the existence of a filter between the two stages in order to protect the second stage from information overload, thus denying access to irrelevant information (Broadbent, 1958).

This model was criticized by many who did not agree with the strictly sequential nature of information processing it implied. In particular, Treisman (1964) proposed a new model named the *Attenuation model*, which consisted of two components that rely on each other to function properly. The first component was the *selective filter*, the second one was the *dictionary*, which symbolized information that required very low threshold in order to be recognized. In the attenuation model, the selective filter is focused on choosing between competing information on the basis of their physical characteristics, such as location, intensity or pitch. Instead, the dictionary allows to select between messages based on their content. This model proposed that more salient stimuli, such as a louder signal, are prioritized because they induce higher levels of activation which are closer to the threshold to access awareness. Unattended messages, on the other hand, are associated with a decrease in their perceived relevance (Treisman, 1964).

A general momentary decrease in the priority for all irrelevant messages can be illustrated with an example: a boy is at an airport searching for a friend who just arrived, who has a violin and a red hat. The boy will be searching at the gate for all individuals who carry a violin and a red hat, quickly disregarding all the others.

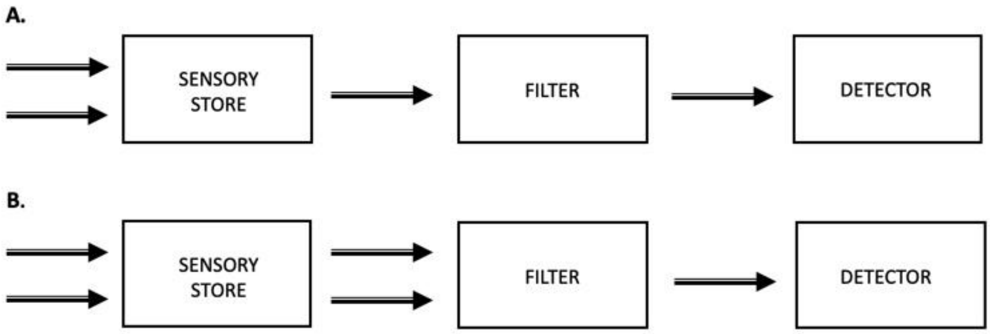


Figure 1 A. Broadbent’s Filter Theory (1958)
B. Filter Theory by Deutsch and Deutsch (1963)

The debate on the working of the attentional filter was further enriched by a model proposed by Deutsch and Deutsch (1963), which claimed that selection occurs much later than what Broadbent and Treisman conceived, at least after a pattern recognition stage, which included higher-order semantic processing of incoming information (Fig.1B). According to this model, all relevant and irrelevant information is analysed for meaning, in parallel and without interference, in order to select an input for further processing leading to awareness. Thus, whether or not an information would be selected is dependent on how it fits with the requirements of the current situation (Deutsch and Deutsch, 1963).

3.3 The “pool” of limited resources

An alternative to the Bottleneck model was the *Capacity model* with the assumption that there is a general limit in the human capacity to perform cognitive tasks. This model also assumed that this limited capacity could be allocated among parallel tasks with considerable freedom (Moray, 1967).

Knowles (1963) claimed for the first time that the human brain has a pool of limited resources (Knowles, 1963). Kahneman (1963) proposed a model in which he equated attention with “cognitive effort” and proposed a flexible capacity limit that could vary depending on task and an individual’s condition. For instance, if the task to perform is high-demanding, a larger amount of resources would be invested, otherwise, if the performance is low-demanding the invested amount of resources would be lower. When the amount of resources available is not enough in order to perform a task, task-performance will be affected (Kahneman, 1963).

Like Kahneman, Norman and Bobrow (1975) have proposed that attention is limited in capacity and controlled centrally. However, they claimed that performance on attention tasks can only be explained by two types of limitations on processing. They theorized a distinction between *resources-limited* and *data-limited* processes. Specifically, performance to some tasks cannot be improved by allocating more resources to them because they rely in a fundamental way on the quality of the input data. For instance, if the perception of stimulus properties did not occur properly, performance will be poor even if more resources were available, because the limit is in the data.

In contrast, resource-limited processes are associated with an improvement in performance in parallel with the increase of resources available, until their depletion (Norman and Bobrow, 1975).

Later on, Posner and Boies (1971) proposed a general limit in performing multiple tasks at the same time. In fact, they demonstrated that performing two tasks in parallel led to a decrease in task-performance in both tasks (Posner and Boies, 1977). McLeod (1977) observed that this limit could be found only when the two tasks were very similar, in fact when performing two different tasks no decreases in performance were reported (McLeod, 1977). Allport et al. (1972) for instance demonstrated that performing two tasks at once, like playing the piano while repeating aloud words, did not lead to a decrease in task-performance (Allport et al., 1972). In this respect, Navon and Gopher (1979) proposed a multiple resources model of attentional capacity, in which tasks are thought to require a specific amount of resources, and secondary tasks will only interfere in so far as they compete for the same resources (Navon and Gopher, 1979).

Based on these studies, McLeod and Posner (1984) suggested that the human brain cannot be envisioned as a single channel of processing, nor relying on one single pool of resources. Conversely, they supposed that the human brain is defined by multiple cognitive resources which are specifically assigned on different forms of information processing (McLeod and Posner, 1984).

However, neither the single capacity models (Kahneman, Norman and Bobrow) nor the multiple capacity models (Allport, Navon and Gopher) seem to provide a complete explanation for divided attention. The main problem with single capacity models is the failure to account for the effect of similarity in dual-task studies. A major weakness of the multiple capacity models is that they do not explain how the separate parts of attention work together. Baddeley (1986) proposed a synthesis theory which attempted to integrate the most reliable features of both approaches. He proposed that attention is controlled by both a central limited capacity processor (the central executive) and individual processors for different tasks (Baddeley, 1986).

Altogether, the intrinsic consequence of having limited resources for cognitive processing is that they are subject to exhaustion, since what is quantitatively limited is destined to undergo a progressive depletion. Up to date, this issue has been mainly investigated in the well-known phenomenon of mental fatigue.

Chapter 4

Mental Fatigue

4.1 What is mental fatigue?

Mental fatigue refers to the subjective feeling that people may experience after working for a prolonged period of time on a demanding cognitive activity (Faber et al., 2012). In this regard, it is a very common phenomenon in modern everyday life which can be experienced by everyone in daily activities such as driving a car for a long time or performing a very long-lasting task. Mental fatigue generally involves tiredness or even exhaustion, an aversion to continue the task at hand, and a decrease in the commitment with the ongoing task (Holding, 1983; Hockey, 1997; Meijman, 2000). It can be objectively measured in terms of performance decrements (Schwid et al., 2003; Lorist et al., 2009), which might be reflected by a long term depletion of cognitive resources and a subsequent increase in the amount and severity of errors being made. In fact, and more importantly, mentally fatigued people often report having a hard time keeping their attention focused and that they are easily distracted (Bartlett, 1943). This suggests that mental fatigue could be associated with impairment in cognitive and behavioural performance (Boksem et al., 2005; Lorist et al. 2005; Van der Linden & Eling, 2006). Van der Linden and colleagues (2003a, 2003b, 2006) demonstrated that people who experienced mental fatigue had difficulties in focusing their attention, in behaviour planning and, in front of negative outcomes, difficulties in changing adaptively their strategies (Van der Linden et al., 2003a; 2003b; Van der Linden et al., 2006). Bocksem et al, (2006) further showed that subjects reported compromised capacity in preparing their responses in an adequate way (Bocksem et al., 2006).

4.2 Mental fatigue and attention

Several studies have examined the relationship between mental fatigue and selective attention (van der Linden et al. 2006; Boksem et al. 2005; Faber et al., 2012).

Van der Linden et al. (2005), for instance, studied the effect of mental fatigue on local versus global processing in a 2 hours local-global task, in which subjects were shown global patterns formed by conflicting local elements (e.g., a global letter H made up of small letters). Fatigued subjects displayed more compromised local rather than global shape processing, which, between the two is thought to rely more heavily on top-down control (van der Linden et al. 2005). Faber and colleagues (2012) investigated whether and how mental fatigue affects selective attention in visual processing by examining differences in processing of task-relevant versus task-irrelevant information. EEG signals, RTs and accuracy were recorded from subjects who performed a two hours Eriksen flanker task, in which a target letter is shown at the center of a three-items string in which the flanking letters may be either neutral or conflicting with the target. Results showed that attention was indeed affected by mental fatigue. Participants, in fact, showed difficulties in suppressing task-irrelevant information, so that specifically in trials in which the flanking letters were conflicting with the target, with increasing time on task they tended to show stronger effects of interference, thus reflecting decreasing response accuracies (Faber et al., 2012).

Furthermore, many studies have demonstrated that mental fatigue impairs attentive mechanisms in different ways (Boksem et al., 2005, Sarter et al., 2001; Summala & Mikkola, 1994; van der Linden et al., 2003; van der Linden et al., 2006). Boksem and colleagues (2005) examined how mental fatigue affects the attentional processes regarding the selection of the relevant information while disregarding all the distracting ones. Participants performed a visual attention task for three hours without rest. Personal level of fatigue, behavioural responses and EEG data were recorded. Results suggested a clear decrement in performance; in fact RTs and error rates increased significantly during the 3 hours of task performance. Attention-related ERP components in the EEG were as well affected by mental fatigue, in fact it seemed that subjects were performing in a more stimulus-driven rather than goal-driven way as a reduction in top-down control was registered (Boksem et al, 2005). These attentional impairments are the consequences of numerous perceptual and cognitive mechanisms. Many other studies agreed with Boksem et al., demonstrating that one of the major effects that it is possible to register under fatigue is a weakened top-down-control on more automatic cognitive processes (Boksem et al., 2005; Lorist et al., 2000; van der Linden et al., 2003). Moreover, as a consequence of reduced top-down modulation of behaviour, actions are more likely to ‘escape’ control, which would lead to a more stimulus driven and compromised cognitive processing, reflecting increased inattentiveness and proneness for errors, which is typical of fatigued people (van der Linden et al. 2003). The most common behavioural manifestations of these effects are longer RTs, increased error rates, as well as difficulty in ignoring distractors. In this regard, particular difficulties in sustained attention to a task have been observed when potentially interfering distractors are present (Boksem et al. 2005; Lorist et al. 2000). The use of distractors represents one way to test attentional control, since it is known that its contribution is crucial in order to overcome the potential detrimental effect exerted by distractors (Peers & Lawrence, 2009). Nonetheless, there are controversial results on this regard. In fact, while an increased distractor effect was found in some fatigue studies (Boksem et al., 2005; Landsdown, 2001), other studies failed in finding an increased interference due to distraction information under fatigue (Lorist et al., 2005; Lorist, 2008). Therefore, these results suggest that the ability to ignore distractors under fatigue may be moderated also by other task characteristics. In fact, Csathò and colleagues (2012) investigated the effects of fatigue in distraction processing with varying perceptual load associated with the processing of the task-relevant target. Participants performed the Eriksen flanker task, as described above, for 2.5 hours without rest. Target letters were presented at three different perceptual load conditions, which differed with respect to the number of items shown in a central stimulus array together with the target: the higher the number of non-relevant items, the higher the cognitive load. Moreover, a peripheral distractor letter was also shown, which could be either congruent, incongruent or neutral with respect to the task relevant item, shown within the central stimulus array. With increasing time on task, the results showed an improvement in responses during the first part of the session, followed by a clear deterioration in performance over time. The detrimental effect of fatigue was registered particularly in the high load condition. However, when considering specifically distraction filtering, they found that it was affected by fatigue at very low perceptual load, but not in the medium or high load conditions, adding important evidence to the literature on how cognitive processes are affected by mental fatigue (Csathò et al., 2012).

In general, therefore, it could be easy to conclude that mental fatigue is the direct result of working for a prolonged period of time: the longer time is spent on a cognitive demanding task, the more mental fatigue will be experienced. However, studies showed that this is not the case. In fact, while mental fatigue can occur also after a relatively short period of working (Sparks et al. 1997; Park et al., 2001), working for a prolonged periods of time does not systematically lead to mental fatigue, for instance when the rewards of working are perceived as high (Siegrist et al., 1997; Van der Hulst and Geaurts, 2001).

4.3 Motivational decline: can it really lead to mental fatigue?

Given that mental fatigue can be strongly affected by motivational factors, some researchers have claimed that mental fatigue is a complex state that involves crucially changes in motivation and mood (van der Linden, 2010). The feeling of fatigue may result from the subconscious analysis of costs and benefits associated with activities to expend or conserve energy (Tops et al, 2004; Boksem et al., 2006). In other words, when the potential rewards for performance are high, people are motivated in engaging or in continuing ongoing activities, even when they require an effort. Conversely, when the perceived energetical costs of task performance exceed the motivation in obtaining reward, the present activity may be abandoned, in order perhaps to engage in another potentially more rewarding activity.

Further studies, however, suggested that the relationship between motivation and mental fatigue might not be so systematic. Gergelyfi et colleagues (2015), for instance, collected various neural, autonomic, psychometric and behavioural signatures of mental fatigue and motivation from participants who had performed a demanding cognitive task for two hours. Results showed that while a motivational decline can occur, causing a progressive disengagement from the task, it cannot be considered as a causal factor in the development of mental fatigue. In fact, an alteration of task engagement alone could not explain mental fatigue, which instead seemed to be the direct consequence of a decrease in efficiency, or availability, of cognitive resources (Gergelyfi et al., 2015).

Chapter 5

Ego Depletion

5.1 What is ego depletion?

As in mental fatigue, in everyday life it is possible to observe another phenomenon that relies as well on the exhaustion of a pool of limited resources. People are used to deal daily with stressful situations that require them to regulate their thoughts, their behaviours as well as their emotions. Self-regulation is an important key to successful human functioning and behaviour. Studies on self-regulatory failures suggested that self-control relies on a pool of limited resources (Baumeister & Heatherton, 1996); if temporarily depleted, this might impair the ability in regulating other seemingly unrelated domains (Vohs & Heatherton, 2000; Richeson & Shelton, 2003; Gailliot et al., 2007; Hagger et al., 2010). This is what the limited-resources model, or the strength model of self-regulation of Baumeister & Heatherton (Baumeister & Heatherton, 1996), affirmed. Studies have shown that following a low-resources availability in self-control, an increase of maladaptive behaviours can be observed (Muraven et al., 2002; Muraven et al., 2005; Stucke & Baumeister, 2006). Importantly, this state of diminished internal resources reduced the efficiency of executive functions, leading to an enhanced likelihood of self-regulatory failure which was defined by Baumeister et al. (2009) as “ego depletion” (Baumeister et al., 2009).

5.2 Ego depletion and emotion regulation: same pool of resources?

Many studies highlighted the connection between emotion regulation and self-regulation. These two forms of regulation, which have been traditionally explored within different fields of research, seemed to rely on the same limited resources. In fact, one of the most common techniques used in order to lead to the depletion of self-regulatory resources is to engage participants in an emotional inhibition task (Baumeister et al., 1998; Muraven et al., 1998; Vohs & Heatherton, 2000; Schmeichel et al., 2003; Gailliot et al., 2007). Accordingly, it has been demonstrated that following the effort to inhibit their emotions during an emotionally provocative film, participants showed subsequent difficulties in regulating their behaviour on a task which implied behavioural control in a different domain, such as avoiding inviting food (Vohs and Heatherton, 2000) or solving very difficult anagrams (Baumeister et al. 1998). These results might also point in the opposite direction, suggesting that being engaged in an effortful self-regulation can subsequently cause emotional dysregulation. In this line, Muraven et al. (1998), with the first of a series of experiments, demonstrated that participants who completed a thoughts-suppression task were subsequently less successful in inhibiting their emotions compared to control subjects (Muraven et al., 1998). Likewise, Schmeichel (2007) demonstrated that using a complex working memory task it was possible to induce self-regulatory depletion that led to failures in emotion regulation in a task which required participants to suppress the facial expression of emotion while viewing a highly aversive video segment (Schmeichel, 2007). Importantly, according to both studies, the effect of self-regulation exerted on emotion regulation was not due to non-specific changes in mood caused by the depletion task itself (Muraven et al., 1998; Schmeichel, 2007). Thus, being engaged in effortful self-regulation might impair the subsequent attempts to exert emotion regulation. Moreover, and more importantly, Wagner & Heatherton (2013) used functional neuroimaging in order to investigate the effects of being involved in effortful self-regulation on the subsequent neural responses to emotional material. They indeed demonstrated that consuming self-regulatory resources led to an exaggerated neural response to emotional material, specifically for stimuli with negative valence. Moreover, they highlighted a consequent failure in recruiting prefrontal regions involved in top-down emotion regulation (Wagner & Heatherton, 2013). Taken together, all the above results offer clear evidence that emotion regulation draws on the same pool of limited resources that are involved in other forms of self-regulation and can be impaired after the depletion of these resources.

5.3 Ego depletion and cognition

Executive functions are the cognitive processes crucially engaged in successful self-control (Hofmann et al., 2012). In fact, the exertion of self-control is required in order to initiate cognitive processing and focus attention on the current task while inhibiting distractions. Executive functions have a key role in inhibiting attentional shifts toward distractors, in updating relevant information in working memory and also in shifting between tasks (Hofmann et al., 2012; Miyake et al., 2000). Although it is still unclear which mechanisms underlie the ego-depletion effect, it has now been widely demonstrated that ego-depletion affects negatively cognitive task performance. In fact, studies have demonstrated that individuals in a state of ego depletion failed more easily in solving anagrams tasks (Baumeister et al., 1998; Muraven et al., 1998). Moreover, ego depletion has also been found to worsen performance in working memory (Schmeichel, 2007) and mental arithmetic tasks (Hagger et al. 2010). Students in a state of ego-depletion had fewer mental capacities available to keep their attention focused on information stored in working memory, and on the online processing of mathematical information, while suppressing simultaneously distracting thoughts or emotions (Bertrams et al., 2015; Bertrams et al., 2013). In order to study whether decreases in task performance were dependent on ego-depletion effects, Lindner et al. (2017) introduced an ecologically valid computer-based session, which allowed to test the interplay between trait self-control and ego depletion (Imhoff et al., 2014; Gillebaart et al., 2015). They found that a personality trait associated with self-control was positively correlated to the effort that individuals put in solving the task. Participants with higher levels of self-control seemed to deplete their self-control resources at a higher pace, supposedly because of their more intense use of mental capacities in order to control attention and process information. They provided evidence that self-control decline over time and ego depletion is indeed a phenomenon that can be easily experienced in daily life (Lindner et al., 2017).

5.4 Self-control resources: can they be replenished?

Many studies explored whether self-control resources can be replenished. Sleep and rest always help in replenishing self-control resources. In fact, it has been demonstrated that well-rested people have better self-control (Baumeister et al., 1996). More interestingly, it has been demonstrated that positive emotions are involved in the replenishment of self-control resources. Tice, Dale and Baumeister (2000) conducted studies in which participants were engaged in two different acts of self-control. In a between-subjects design, some of them received an induction of positive mood, the remaining were induced to perceive a negative mood. Results reflected that the positive mood group showed less evidence of ego depletion, suggesting that this affective state could counteract the depleting effect due to the resource-demanding task (Tice et al., 2000). Similar results were obtained also by Tice et al. (2007), demonstrating again that inducing positive emotions, as well as a positive mood, are helpful in counteracting the effect of ego depletion (Tice et al., 2007). Moreover, many other beneficial effects of positive emotions have been proposed to preserve self-regulation resources, increasing arousal (Thayer, 1989) and counteracting the physiological effects caused by negative emotions (Fredrickson, 2001; Fredrickson & Levenson, 1998; Fredrickson et al., 2000).

Other studies highlighted the importance of motivational factors in this respect. In fact, they have demonstrated that increasing the intrinsic motivation to perform a task, such as providing monetary or altruistic rewards in return for task performance, improved self-regulation (Moller et al., 2006; Muraven et al., 2008; Vohs et al., 2012). Furthermore, Muraven et al. (2003) also demonstrated that motivation affects the consumption of self-regulation resources. In fact, individuals could compensate for a lack of self-control resources with increased motivation (Muraven et al., 2003). Thus, the moderating influence that motivation exerts on self-control suggests that depletion does not systematically lead to self-control failure.

5.5 Aim of this work

Considering the evidence reviewed above, it seems clear that the human brain constantly deal with an enormous amount of information that cannot be processed at once since it does not have sufficient processing capacity in order to analyse in detail all the information it receives (Tsotsos J.K. et al., 1995; Marois and Ivanoff, 2005; Dux et al., 2006). Given limited processing resources, visual selective attention has the role to differentiate between competing stimuli in order to facilitate the processing of stimuli that are relevant for adaptive behaviour while filtering out the irrelevant ones (Chelazzi et al., 2011; Desimone & Duncan, 1995; Raynold & Chelazzi, 2004).

From an evolutionary perspective, stimuli that signal danger or threat get higher processing priority compared with competing stimuli (Carretié et al., 2000; Pessoa et al., 2005; Cacioppo & Gardner, 1999). Accordingly, there is evidence that emotional stimuli are very powerful in attracting attention (Ohman et al., 2001; Vuilleumier et al., 2001; Anderson et al., 2003; Phelps et al., 2006) and can interfere with the overall deployment of attentional resources. Indeed, a bias towards the prioritization of emotional stimuli is always likely to occur where there is competition among stimuli to access the limited attentional resources of an individual (Ohman et al., 2001; Vuilleumier et al., 2001; Anderson et al., 2003), even if they are task-irrelevant, and therefore should be ignored (Hodsoll et al., 2011; Yiend, 2010). In fact, emotional stimuli are processed faster and easily gain access to conscious perception, either because they are processed automatically (Vuilleumier et al., 2001), or because sufficient cognitive resources are available (Pessoa et al., 2002). Thus, avoiding or preventing the processing of emotional stimuli requires a conspicuous amount of resources that, if engaged for a prolonged period of time and under high-cognitive demanding tasks, can undergo depletion, and eventually lead to the very common phenomenon of mental fatigue (Faber et al., 2012). The same resources will be drawn from the need to exert self-control to perform a sustained task which requires the inhibition of distracting information, even when there are no emotional contents involved

(Baumeister et al., 1998; Muraven et al., 1998; Vohs & Heartherton, 2000; Schmeichel et al., 2003; Gailliot et al, 2007).

This work was planned with the aim of directly exploring the possibility that the resources which are depleted during the inhibition of irrelevant emotional distractors are crucially involved in attentional processing, and represent a set of limited cognitive resources specifically engaged for the working of visual selective attention. Differently from what typically emerges in mental fatigue, we expect that such depletion might occur in a short period of time, under conditions of very heavy and persistent distraction. This perspective is entirely new, because no one has investigated before the depletion of such limited attentional resources.

We will describe a number of visual selective attention experiments, based on the Attentional Capture task, in which subjects had to detect and discriminate a target stimulus while ignoring a salient irrelevant distractor which could appear in a proportion of trials. Crucially, in order to increase the cognitive taxing and therefore the possibility of leading to fatigue, we decide to set a strong pace throughout the experimental session, reducing the time interval between the end of one trial and the start of the next. Moreover, in order to, on the one hand, increase the attentional load and, on the other hand, the distraction information to filter out, we introduced in our paradigm the display of irrelevant stimuli with emotional content with different valence. Subjects were instructed to focus their attention on the main task (and discriminate the target stimulus), while ignoring both the emotional image that appeared prior to the task-relevant stimuli, and the salient distractor which could appear simultaneously with the target. Importantly, the presentation of the emotional images might have also led to an effort to inhibit the emotional response that might be elicited by their appearance. Since previous experiments proved that inhibiting emotional responses caused a large consume of processing resources, by introducing this manipulation, we intended to add a cost in attentional processing resources that might impair also the exertion of self-control. Thus, considering all these variables, we expected a higher and faster consume of attentional resources with time on task, and therefore their depletion in a very brief period of time (i.e. one hour-session). The dependent variable taken in order to measure the depletion of attentional resources was the effect of attentional capture triggered by the salient distractor appearing during target display. In line with our assumptions this cost was expected to increase with time on task, reflecting the progressively reduced availability of attentional processing resources.

Chapter 6

Depleting the brain's attentional resources: a new experimental paradigm

6.1 Experiment 1

As detailed in the first Chapters, cognitive resources are limited (Wickens, 1980, van der Linden D., et al., 2003; van der Linden D., 2011), so that for instance when people attempt to perform two tasks at once their performance will reflect costs, such as greater processing time or/and larger error rates, compared to when the same tasks are performed one at a time. Moreover, many studies have demonstrated that after several hours spent performing a cognitively demanding task a state of mental fatigue will occur, which is also associated with an impairment of cognitive and behavioural performance. In fact, fatigued people often report having a hard time in keeping their attention focused on the ongoing task and being easily distracted. Additionally, reduced levels of motivation are also observed, with respect to continuing to work on the task at hand, as well as difficulties in planning and changing strategies (van der Linden D., et al., 2003; van der Linden D., 2011; Meijman T.F., 1997; Faber, et al., 2012).

Therefore, it is plausible to claim that mental fatigue has a widespread effect on the deployment of limited cognitive resources. Mental fatigue however has been typically investigated in situations in which subjects are required to perform a given task for several consecutive hours. No studies, however, have observed effects that can be associated with mental fatigue within one or two-hour sessions. In this experiment, our aim was to investigate whether, by heavily engaging visual selective attention in a continuous manner, we could observe a depletion of cognitive resources specifically dedicated to attentional mechanisms, and therefore give rise to a form of "attentional fatigue" within a relatively short period of time, i.e., 1 and a half hour..

To this purpose, we developed a new version of the Attentional Capture (AC) task (Theeuwes, 1994), similar to the one introduced by Tommasi, et al. (2015). As explained in the previous sections, the AC task is designed to study the exogenous capture of attention by allowing performance to be compared across trials with and without a salient-task irrelevant distractor (singleton). It is also used in order to reflect the competition between the top-down and bottom-up mechanisms of attentional control, so that any changes detected in task performance may reflect the efficacy with which the two systems manage to resist distraction (Attentional Capture).

In our experiment, participants were asked to search for a task relevant item while ignoring a salient irrelevant distractor which could appear in a proportion of trials, engaging therefore both attentional mechanisms involved in target selection as well as others primarily involved in the filtering of distraction (Noonan, M.P., et al. 2016). The main task was similar to the one adopted by Tommasi et al. (2015), although in order to make it suitable for our current purposes some important changes were introduced.

Crucially, in order to increase the cognitive taxing and therefore the possibility of leading to fatigue, we decided to set a strong pace throughout the experimental session, reducing the time interval between the end of one trial and the start of the next. Moreover, in order to tax specifically attentional processes, we decided to increase the attentional load imposed by the task, introducing an additional manipulation that should have driven to a faster depletion of attentional resources.

Specifically, a full-screen image with a variable emotional content was displayed prior to the search array. These images were completely task-irrelevant. Despite their being irrelevant for the required task, converging evidence suggests that emotional stimuli tend to attract or ‘capture’ attention automatically, interfering with the ongoing task (Fox *et al*., 2000; Vuilleumier & Schwartz, 2001*a*; Anderson, 2005; Vuilleumier & Driver, 2007, Verbruggen F., et al., 2007). For this reason, these images might have acted as strong distractors, capable of reducing the amount of attentional resources available for the upcoming trial.

Beyond their capacity to capture attention, emotional stimuli are also capable of activating the self-regulatory mechanisms that control and modulate emotional responses (Muraven et al., 1998; Vohs & Heatherton, 2000; Schmeichel et al., 2003; Gailliot et al., 2007.). These self-regulatory operations are known to consume resources that subsequently appear as depleted. In fact, it has been observed that when people override their emotional responses, they are subsequently less successful at controlling themselves or responding actively, even in a seemingly unrelated sphere of activity, and experience so the so-called phenomenon of Ego Depletion (Baumeister, Bratslavsky, Muraven, & Tice, 1998;

Muraven, Tice, & Baumeister, 1998; Vohs & Heatherton, 2000, Baumeister, 2014). Thus, following the evidence reported in the literature, we hypothesized that the display of emotional stimuli prior to the task relevant information in each trial could represent an ideal way to overload the systems involved in attentional processing. Together with the fast pace of the task, and therefore the limited time allowed for any rest in between trials, we expected to observe a progressive deterioration of attentional performance during the course of the experimental session, possibly suggesting the ongoing depletion of attentional resources. Differently from a generalized effect of fatigue, which might have nevertheless appeared during the session, we expected this phenomenon to be specifically attentional in nature, and result for instance in greater costs associated with the filtering of salient distractors when they were present together with the to-be-discriminated target.

6.2 Materials and methods

Participants

Twenty-one subjects (11 males; mean age ± SD, 24.86 ± 1.80) took part in this Experiment. Two participants however had to be excluded from the final sample. One of them did not complete the entire session and the other one did not reach the accuracy threshold value of 75%. All subjects comprised in the final sample (9 males; mean age ± SD, 24.79 ± 1.87) were right-handed and with normal or corrected-to-normal vision. Most of the participants were students at the University of Verona, Italy. None of them had previously taken part in similar or related studies, and they were all naive as to the purpose of the study. All the participants received fixed monetary compensation (10 euros) and gave written informed consent before participation. The protocol was approved by the Review Board for Studies involving Human Participants of the University of Verona, Italy.

Apparatus

The experiment and stimuli were created using OpenSesame software for Windows (Mathôt et al., 2012). Stimuli were presented on a 17-in CRT monitor. Participants were tested in a sound-attenuated, dimly lit room. The viewing distance was held constant at 57 cm during the whole session using a chin rest.

Design and procedure

The experimental session consisted of a first initial practice block, which was only necessary in order to allow subjects to become experienced with the task required and one Depletion block, which consisted of the main experimental phase.

The main task was similar to the one adopted by Tommasi et al. (2015) (Tommasi et al., 2015). At the beginning of each trial a stimulus display appeared on the computer monitor, comprising six identical diamond shapes of 1.2° of visual angle, placed at 3.6° from the center of the screen, all colored in either red (RGB color coordinates: 235, 0, 0; luminance: 14.6 cd/ m^2) or green (RGB color coordinates: 0, 168 , 0; luminance: 14.6 cd/ m^2). After an interval lasting 100 or 200 ms (i.e., referred to as the "pre-display"), the top or the bottom corner of one of these placeholders disappeared. This item was the target, and subjects were instructed to discriminate its shape by pressing, with their right hand index or middle finger, key "1" of the numerical keypad if the base of such pentagon was at the top or key "2" if it was at the bottom (Fig.1). The "top" or "bottom" response required by the target was equally likely within the experiment. In 50% of trials, the so-called "distractor condition", simultaneously with the target onset, one of the other five diamonds changed its color (becoming red instead of green, or vice versa) as well as its orientation (45° rotation, becoming a square). This highly salient stimulus was completely irrelevant for the task, but given its features was assumed to capture attention automatically – via bottom-up mechanisms – and pose a great challenge for target selection. Participants were encouraged to focus only on the target while completely ignoring the distracting element.

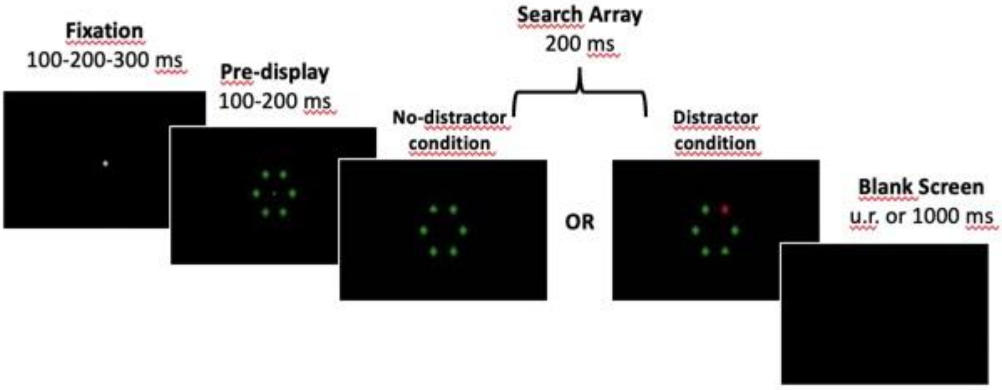


Fig.1 Graphic illustration of an example trial from the practice block.

During practice, each trial began with a white central fixation point display, against a black background, lasting 100, 200 or 300 ms. This was followed by the trial events described above. After target onset (and distractor onset in distractor trials), the search display remained visible for 200 ms and it was followed by a blank screen that stayed on until the participant’s response, or for a maximum duration of 1000 ms. A new trial began immediately afterwards, as no intertrial interval was included (Fig.1).

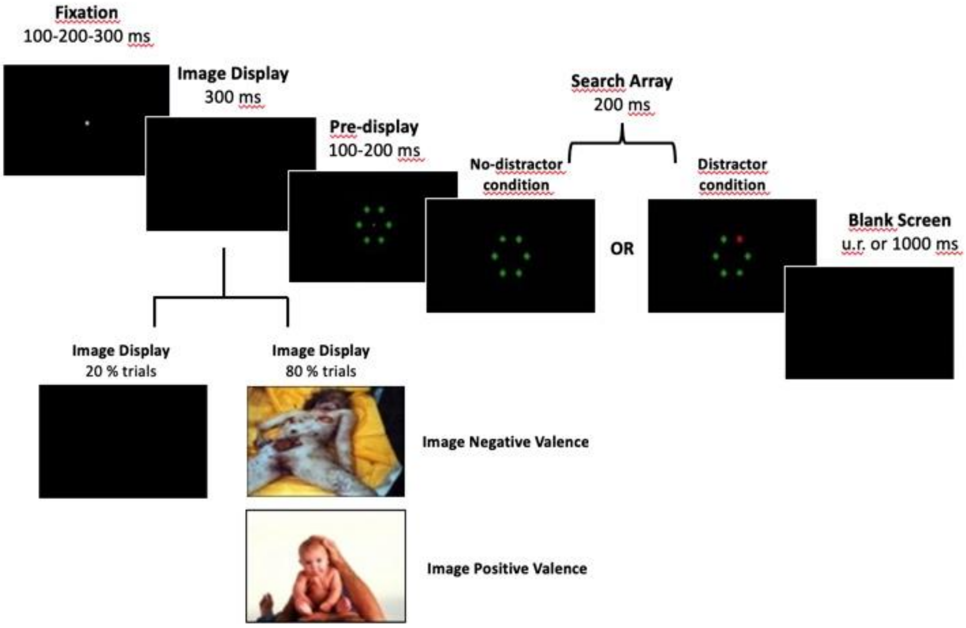


Fig.2 Graphic illustration of example trial for the Depletion Block.

In the Depletion Block, after the central fixation point display and before the onset of the stimulus array a full screen image (Codispoti et al., 2007) with either positive or negative emotional valence was presented for 300 ms in 80% of the trials (40% positive and 40% negative valence) (Fig.2). In the remaining 20% of trials a black screen appeared for the same amount of time. For this purpose, a total of 384 images, 192 with a positive valence and 192 with negative valence were chosen from the International Affective Picture System (IAPS) Catalogue and each of these was repeated at random four times during the course of the experiment (Lang, et al., 1999).

Again, participants were instructed to focus on the target in order to discriminate the position (top or bottom) of the base of this pentagon shape, ignoring both the emotional response that might have been engendered by the images and the salient distractor when they were present in the trial.

Participants completed the initial Practice block of 120 trials, followed by the Depletion block. Overall, the Depletion block lasted approximately one hour and fifteen minutes and consisted of 1920 trials, of which 1536 (80%) preceded by an image with emotional valence (Image present trials) and 384 (20%) trials preceded by the black screen (Image absent trials), displayed in a random order. Orthogonally, the salient distractor was present in 50% of cases (distractor trials), and absent in the remaining ones (no distractor trials). No pauses were provided within the experiment.

At the end of the computerized experiment, participants completed a number of self-report questionnaires, assessing different aspects of their personality and emotional regulation traits: the Eysenck Personality Questionnaire-Revised (EPQ-R), assessing three major dimensions of personality which are Neuroticism, Psychoticism and Extraversion-Intraversion (Eysenck, S.B.G., et al., 1985), the Eysenck's Impulsivity Inventory (IVE), assessing the personality traits of impulsivity, venturesomeness and emphaty (Eysenck, H.J., & Eysenck, S.B.G., 1991), the State-Trait Anxiety Inventory (STAI-Y-X1 and STAI-Y-X2) (Kabakoff, R.I., et al, 1997), measuring trait and state anxiety and the Difficulties in Emotion Regulation Scale (DERS), measuring emotion regulation problems

(Gratz, K.L., & Roemer, L.,2004). The collection of these data however was carried out within the framework of a larger study, involving a much greater sample of participants and the aim of which was beyond the scope of this research project. For this reason, the information obtained from these questionnaires will not be discussed further.

Data analysis

Analyses were performed using R 3.4.3 (R Core Team, 2016) on performance during the experimental block. Repeated-measures analyses of variance (ANOVAs) were performed on reaction times (RTs) and error rates, excluding trials with a RT below 200 ms, which were considered as anticipated responses. We also excluded from further analysis trials in which the RT fell outside ±3 SDs from the mean value for each participant and trial type (on average, less than 1% of the data were excluded). When appropriate, p values for statistical significance were adjusted for multiple comparisons (Holm–Bonferroni correction).

Overall analysis performance

A first comprehensive analysis of task performance was conducted on the whole dataset acquired during the Depletion block. Mean RTs of correct responses and error rates were entered into within-subject ANOVAs including as factors Distractor Presence (present or absent), Image Presence (present or absent), Block (1-4) and Predisplay duration (100 or 200 ms).

Results

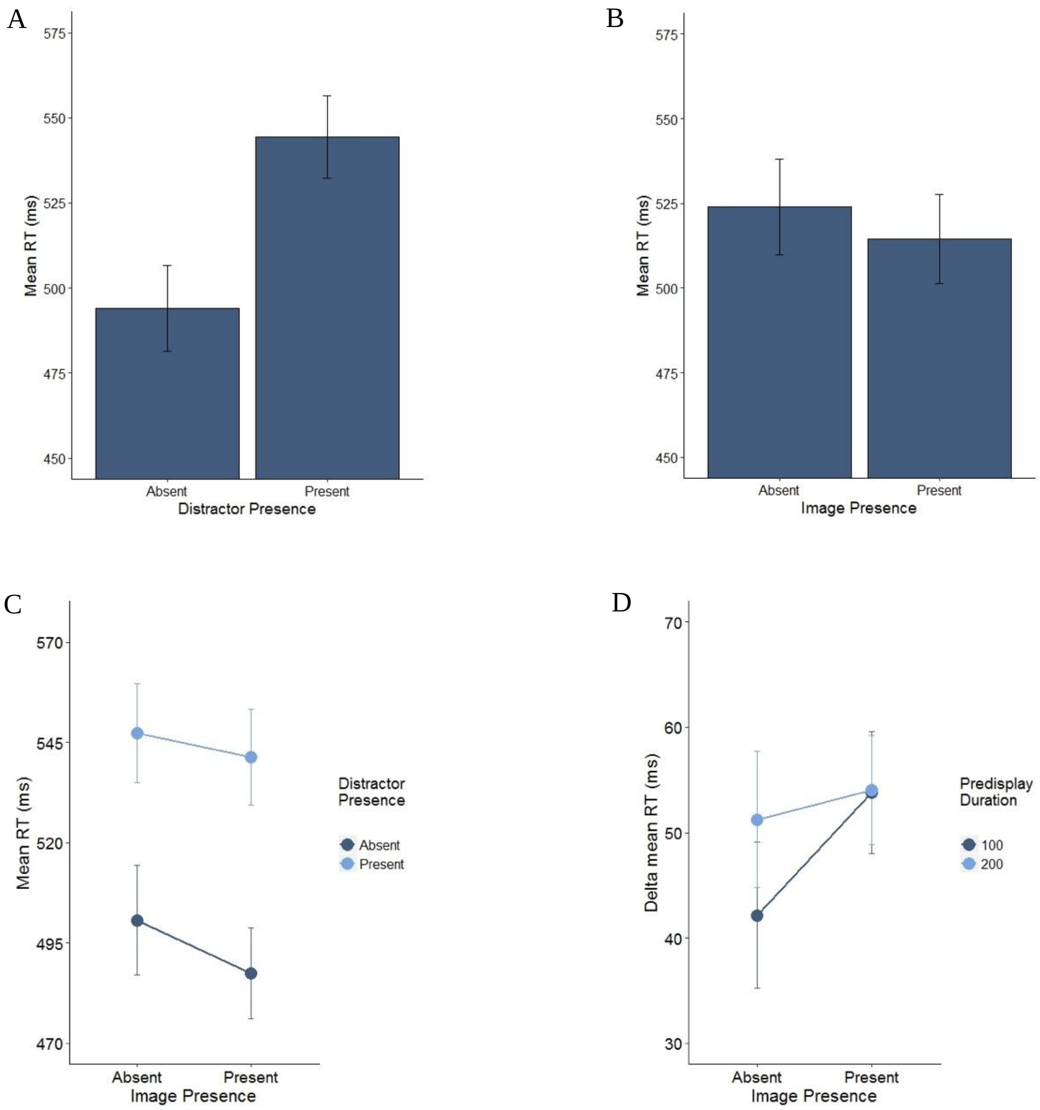
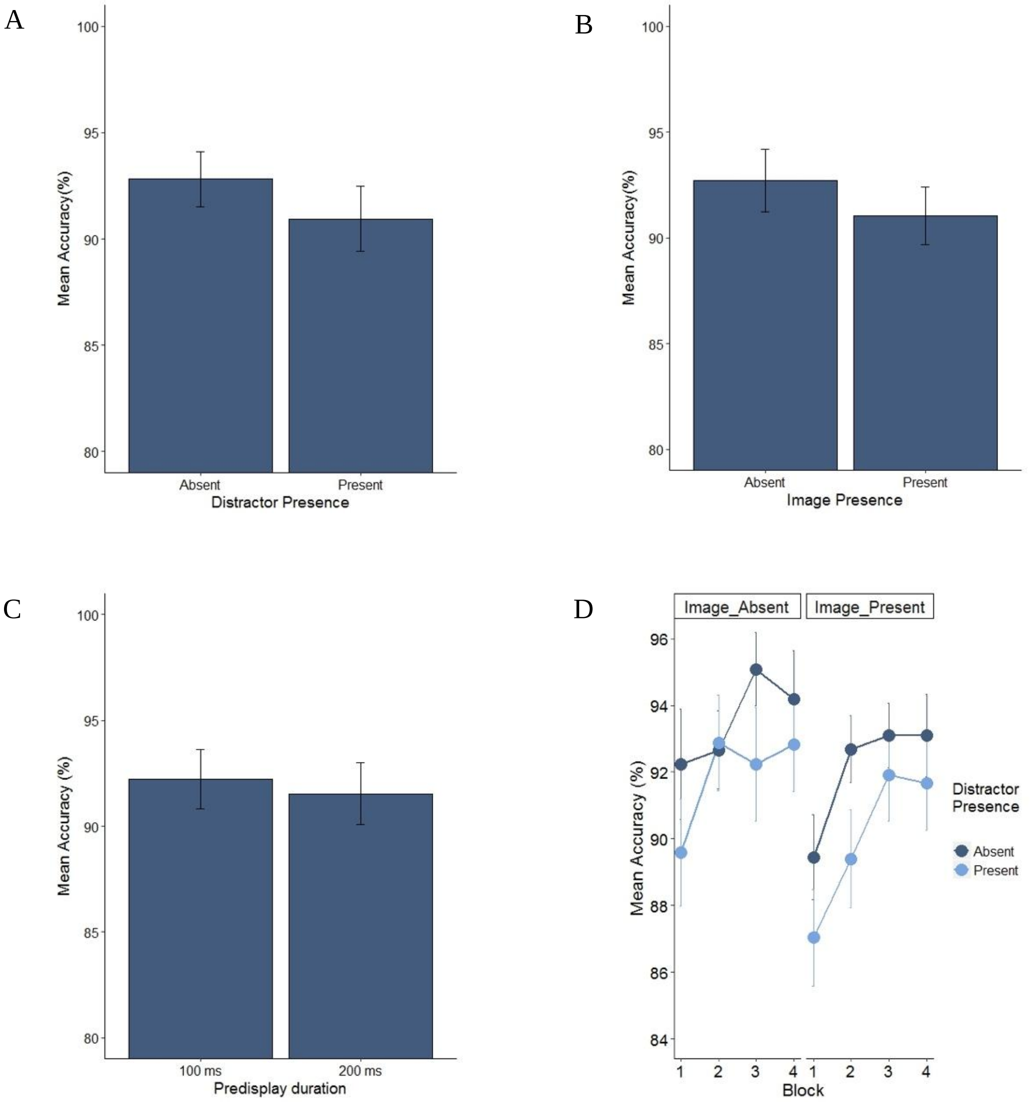


Fig.3 RTs of the overall analysis performance. A. Main effect Distractor Presence. B. Main effect Image Presence. C. Interaction Distractor Presence as function of Image Presence. D. Cost of Distractor as function of Image Presence and Predisplay duration.

Reaction times. The ANOVA revealed a significant main effect of Distractor Presence, $F_{(1,\ 18)} = 669.87$, $p < .001$, ηp2 = .973, with faster responses in the Distractor-absent (494.03 ms ± 26) compared to the Distractor-present condition

(544.33 ms ± 29) (Fig.3 panel a). This difference reflects the typical attentional capture effect, suggesting that a salient visual distractor impairs performance to the main task by attracting attentional resources to the detriment of other ongoing computations. A significant main effect of Image was also found, $F_{(1, 18)}$ =17.99, p < .001, ηp2 = .499 (Fig.3 panel b). Indeed, the presence of the emotionally salient image seemed to lead to faster RTs. The main effect of Block was significant, $F_{(3, 54)}$ = 8.05, p < .001, ηp2 = .389, reflecting slower responses in the initial part of the session (mean ± SE; Block 1 = 537.62 ms ± 28, Block 2 = 516.49 ms ± 27, Block 3 = 511.84 ms ± 27, Block 4 = 510.76 ms ± 27; Block 1 vs Block 2: $t_{(151)}$ = 6.87, p < .001; Block 2 vs Block 3: $t_{(151)}$ = 2.08, p = 0.03; Block 3 vs Block 4: $t_{(151)}$ = 0.44, p = 0.65). The main effect of Predisplay duration was also significant, $F_{(1, 18)}$ =102.79, p < .001, ηp2 = .851, showing faster RTs in the 200 ms compared to the 100 ms condition. The interaction between Distractor and Image presence was marginally significant, $F_{(1, 18)}$ = 4.38, p = 0.0507, ηp2 = .195 (Fig.3 panel c). Since the considerable importance of this interaction with respect to our aims of research, we decided to assess more directly this effect by taking into account the distractor cost, namely, the difference between distractor-present and distractor-absent condition. This interaction was due to the fact that although in both the Distractor-present and absent trials RTs were faster in the Image present condition (Image-present vs. Image-absent for Distractor-present trials: $t_{(18)}$ = 2.54, p = 0.02; Image-present vs. Image-absent for Distractor-absent trials: $t_{(18)}$ = 4.05, p = 0.001), the cost due to the presence of the Distractor was slightly higher in trials in which an Image was present (difference in ms between Distractor-present vs. Distractor-absent for Image-present trials = 53.91 ms vs. Distractor-present vs. Distractor-absent for Image-absent trials = 46.69 ms; $t_{(151)}$ = -2.28, p = 0.02). This finding, albeit marginally significant, suggested that indeed the presence of an emotional image had a detrimental impact on attentional processing, so that the already costly filtering of a salient irrelevant distractor was amplified if an irrelevant image had preceded the display of the task-relevant information. The interaction between Distractor Presence and Image Presence was also involved in a marginally significant three-way interaction with Predisplay duration $F_{(1, 18)}$ = 3.36, p = 0.083, ηp2 = .157 (Fig.3 panel d). The principal difference was observed in the shorter Predisplay duration (100 ms) since there was a significant difference in Distractor cost between the Image-present and Image-absent condition (Cost of Distractor for Image-present vs. Image-absent trials in shorter Predisplay duration = 53.81 ms vs. 42.14 ms, $t_{(75)}$ = -2.53, p = 0.01). Whereas, in the longer Predisplay duration (200 ms) the cost of Distractor was constant over the two Image conditions (Cost of Distractor for Image-present vs. Image-absent trials in longer Predisplay duration = 54.01 ms vs. 51.23 ms, $t_{(75)}$ = -0.64, p = 0.51). All the remaining effects were far from being significant.



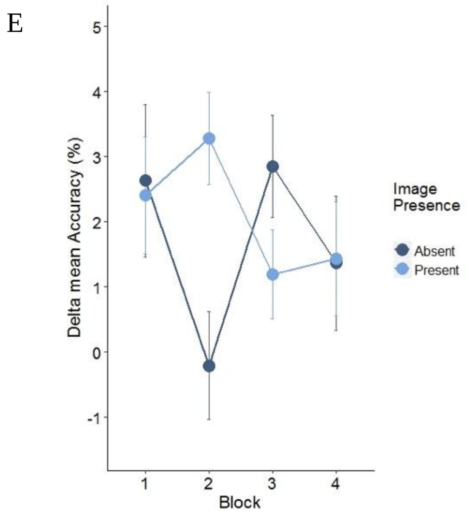


Fig.4 Accuracy rates of the overall analysis performance. A. Main effect Distractor Presence. B. Main effect Image Presence. C. Main effect of Predisplay duration. D. Interaction Distractor Presence as function of Image Presence and Block. E. Cost of Distractor as function of Distractor Presence, Image Presence and Block.

Accuracy rates. The ANOVA on the accuracy rates revealed a main effect of Distractor Presence, $F_{(1, 18)} = 6.50$, $p = 0.02$, $\eta p2 = .265$, with a lower accuracy in distractor present trials, further confirming the disruptive effect of distractors on task performance and the suitability of our paradigm in measuring such attentional capture effect (Fig.4 panel a). There was also a significant main effect of Image Presence, $F_{(1, 18)} =14.86$, $p = 0.001$, $\eta p2 = .452$, that, differently from what we found in RTs, resulted in impaired performance in the Image-present compared to the Image-absent condition (Fig.4 panel b). Indeed, it is possible that the presence of such a salient image prior to the stimulus display might have given rise to a state of nonspecific alertness which on one hand might have speeded task responses, while reducing their accuracy, as in typical speed-accuracy trade-offs. The significant main effect of Block, $F_{(3, 54)} = 9.14$, $p < .001$, $\eta p2 = .408$, revealed, that responses became more accurate at the end of the session (mean Block 1 = 89.57, Block 2 = 91.90, Block 3 = 93.08, Block 4 = 92.94; Block 1 vs Block 2: $t_{(151)} = -4.69$, $p < .001$; Block 2 vs Block 3: $t_{(151)} = -2.39$, $p = 0.01$; Block 3 vs Block 4: $t_{(151)} = 0.29$, $p = 0.76$). The main effect of Predisplay duration was marginally significant, $F_{(1, 18)}$ =3.40, p = 0.08, ηp2 = .158 (Fig.4 panel c). This potential effect, was also opposite to what found with respect to RTs, with lower accuracy in trials with a longer predisplay interval, and similarly to the previously discussed effect of Image presence suggests the emergence of a speed-accuracy trade-off. The triple interaction involving Distractor Presence by Block by Image Presence was also marginally significant, $F_{(3, 54)}$ = 2.49, p = 0.06, ηp2 = .393 (Fig.4 panel d), suggesting a possibly very interesting relationship between the critical factors considered in our study.

The Distractor cost in the Image-present and Image-absent condition was kept constant among Blocks, except in Block 2 where a significant difference was highlighted (Cost of Distractor for Image-present vs. Image-absent trials in Block 1 = 2.63 vs. 2.40, $t_{(37)}$ = 0.16, p = 0.87, Block 2 = -0.20 vs. 3.28, $t_{(37)}$ = -2.84, p = 0.007, Block 3 = 2.85 vs. 1.19, $t_{(37)}$ = 1.31, p = 0.19, Block 4 = 1.36 vs. 1.43, $t_{(37)}$ = -0.05, p = 0.95) (Fig.4 panel e).

Impact of emotional valence on task performance

The results obtained from the overall analysis of the data suggested that, in line with what we expected, the emotional Images shown at the beginning of each trial had a general impact on task performance. Next, we wanted to explore more specifically if the effects on attentional processing assessed by the Distractor cost, could be further affected by the valence (positive and negative) of the images shown. Therefore, we performed new within-subjects ANOVAs on the 80% of the trials in which an image was displayed, considering also its either positive or negative valence. The factors in the ANOVAs were Distractor Presence (present or absent), Image Valence (positive or negative), Block (1-4), and Predisplay duration (100 or 200 ms).

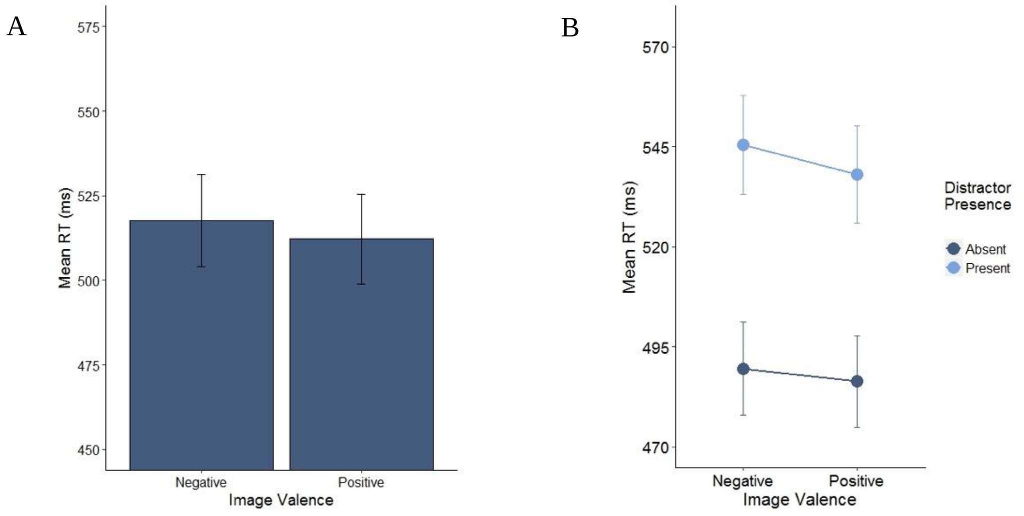


Fig.5 RTs for the impact of emotional valence on task performance. A. Main effect of Image Valence. B. Interaction Distractor Presence as function of Image Presence.

<u>Reaction times</u>. As in the overall analysis, the main effects of Distractor Presence, $F_{(1, 18)} = 1131.58$, $p < .001$, ηp2 = .984, Block, $F_{(3, 54)} = 9.99$, $p < .001$, ηp2 = .412 and Predisplay duration, $F_{(3, 54)} = 9.99$, $p < .001$, ηp2 = .833, were significant, and their trend was perfectly in line with what had already emerged. More interestingly, the ANOVA revealed a significant main effect of Image Valence, $F_{(1, 18)} = 16.86$, $p < .001$, ηp2 = .483, reflecting slower RTs when negative images were presented compared to the positive ones (Fig.5 panel a). The interaction between Distractor Presence and Image Valence was marginally significant, $F_{(1, 18)} = 4.27$, $p = 0.05$, ηp2 = .191 (Fig.5 panel b). This interaction was due to the fact that although in both the Distractor-present and absent conditions RTs were faster when images with positive valence were shown (Positive Valence vs. Negative Valence for Distractor-present trials: $t_{(18)} = -4.01$, $p = 0.001$; Positive Valence vs. Negative Valence for Distractor-absent trials: $t_{(18)} = -2.27$, $p = 0.03$), the cost associated with distractor presence was higher in trials in which the Image shown had a negative valence (difference in ms between Distractor-present vs. Distractor-absent for Negative Valence Image = 55.91 ms; Distractor-present vs. Distractor-absent for Positive Valence Image = 51.66 ms). This finding suggested therefore that emotional images with a negative valence pose a heavier

computational load on attentional mechanisms, resulting in increased attentional capture effects in the current trial. The interaction between Block and Predisplay duration was also significant, $F_{(3, 54)} = 5.73$, $p = 0.001$, ηp2 = .481. Although the difference between the two Predisplay durations (100 ms vs.200 ms) was significant in all Blocks, this effect was significantly greater in the first block compared to the others (100 ms vs. 200 ms by Block 1: $t_{(18)} = 8.32$, p = 5.5400e-07; 100 ms vs. 200 ms by Block 2: $t_{(18)} = 6.36$, p = 1.0844e-05; 100 ms vs. 200 ms by Block 3: $t_{(18)} = 7.08$, p = 3.9420e-06; 100 ms vs. 200 ms by Block 4: $t_{(18)} = 6.02$, p = 1.0844e-05).

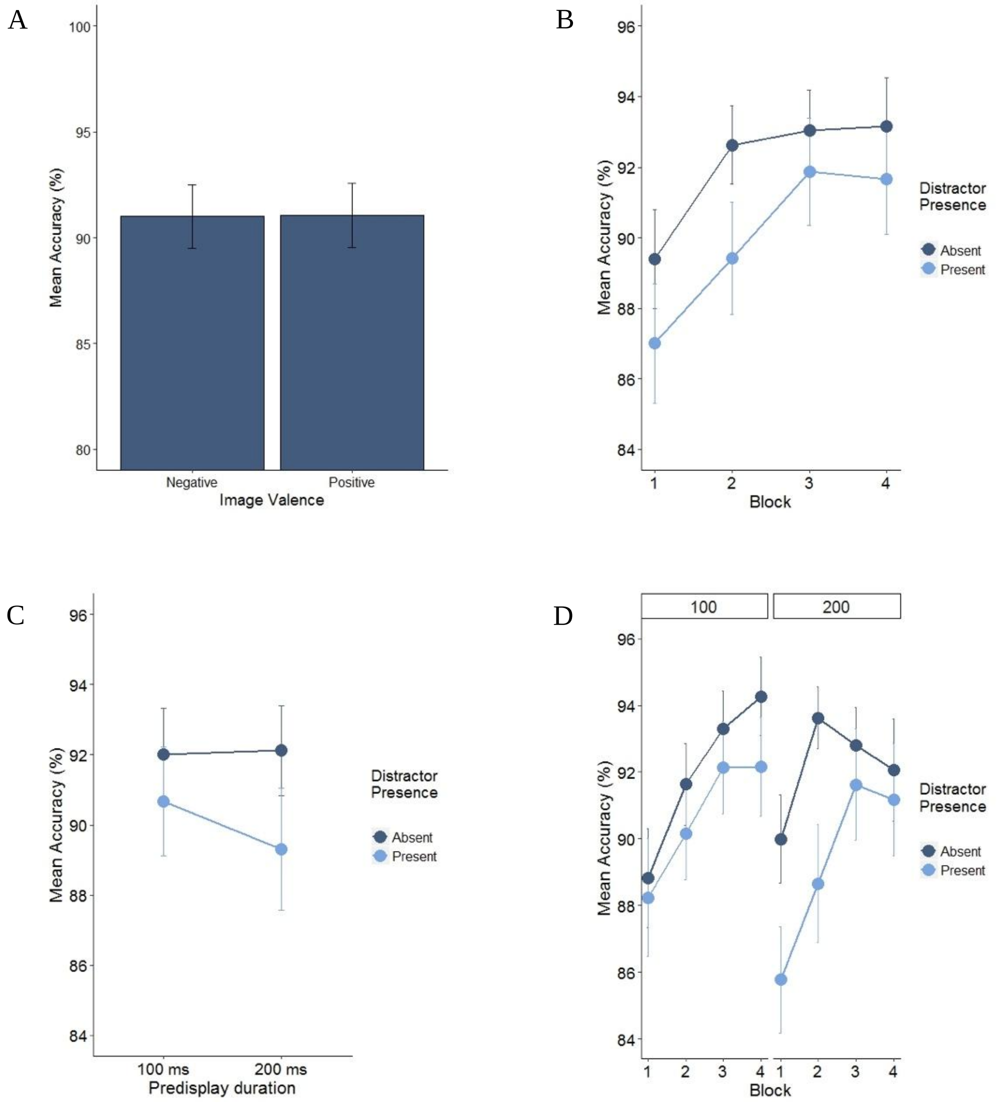


Fig.6. Accuracy rates for the impact of emotional valence on task performance. A. Main effect Image Valence. B. Interaction Distractor Presence by Block. C. Interaction Distractor Presence as function of Predisplay duration. D. Interaction Distractor Presence as function of Block and Predisplay duration.

Accuracy rates. The ANOVA revealed a significant main effect of Distractor Presence, $F_{(1, 18)} = 10.49$, $p = 0.004$, $\eta p2 = .368$, and Block, $F_{(3, 54)} = 8.77$ $p < .001$, $\eta p2 = .411$, confirming what already found in RTs and in the previous analysis. In this analysis, the main effect of Image Valence or its interaction with the other factors did not reach statistical significance (Fig.6 panel a). The interaction between Distractor Presence and Block, was marginally significant, $F_{(3, 54)} = 2.44$ $p = 0.07$, $\eta p2 = .271$, suggesting that although accuracy was higher in the Distractor-absent condition in all Blocks, the cost due to distractor presence (i.e., the difference between Distractor present and absent trials), was only significant in Blocks 1, 2 and 4 (Difference between Distractor-present vs. Distractor-absent by Block1= 87 vs. 89.40, $t_{(75)} = 3.27$, $p = 0.001$, Block 2= 89.41 vs. 92.63, $t_{(75)} = 4.38$, $p < 0.001$, Block 3= 91.87 vs. 93.05, $t_{(75)} = 1.65$, $p = 0.10$, Block 4= 91.66 vs. 93.16, $t_{(75)} = 2.08$, $p = 0.04$) (Fig.6 panel b). The interaction between Distractor Presence and Predisplay duration were also marginally significant , $F_{(1, 18)} = 4.05$ $p = 0.05$, $\eta p2 = .183$, indicating that the cost due to distractor presence was higher in trials with a predisplay interval of 200 ms (Difference between Distractor-present vs. Distractor-absent in the shorter Predisplay duration = 90.67 vs. 92, Difference between Distractor-present vs. Distractor-absent in the longer Predisplay duration = 89.30 vs. 92.12, $t_{(151)} = -2.08$, $p = 0.03$)(Fig.6 panel c). Interestingly, the triple interaction between Distractor Presence, Block and Predisplay duration was significant, $F_{(3, 54)} = 3.04$ $p = 0.03$, $\eta p2 = .293$ (Fig.4d). To better understand this triple-way interaction, we performed two separate ANOVAs, considering separately trials with different Predisplay durations. In these analyses, the interaction between Distractor Presence and Block was significant only in the condition of Predisplay duration of 200 ms, $F_{(3, 54)} = 2.80$, $p = 0.04$, $\eta p2 = .276$ whereas, it was far from being significant with a predisplay of 100 ms , $F_{(3, 54)} = 0.50$ $p = 0.68$. In trials with a 200 ms predisplay duration, the cost due to the salient distractor was statistically significant only in the first two Blocks (Distractor-absent vs. Distractor-present by Block 1: $t_{(18)} = 3.49$, $p = 0.007$; Distractor-absent vs. Distractor-present by Block 2: $t_{(18)} = 3.93$, $p = 0.003$; Distractor-absent vs. Distractor-present by Block 3: $t_{(18)} = 1.06$, $p = 0.30$; Distractor-absent vs. Distractor-present by Block 4: $t_{(18)} = 2.14$, $p = 0.091$) (Fig.6 panel d).

6.3 Discussion

The aim of this experiment was that of directly exploring the possibility that the cognitive resources associated with attentional mechanisms are limited and can be depleted. Differently from what found in the mental fatigue phenomenon, we expected that such depletion could occur, under conditions of very heavy and persistent distraction, in a short period of time (i.e. one-hour session). To this aim, in order to, on the one hand, increase the attentional load and, on the other hand, increase the distraction information to be filtered out, we introduced in our paradigm emotional stimuli, known as powerful retainers of attention, with either positive or negative valence.

The results obtained in this series of analyses, first of all demonstrated the efficacy of our paradigm in giving rise to attentional capture (Theeuwes, 2004). Indeed, performance varied as a function of distractor presence. In particular, a decrease in performance was registered in the distractor-present condition compared to the distractor-absent condition, suggesting that bottom-up attentional mechanisms were quickly engaged by this salient stimulus, to the detriment of the processing of concurrent task relevant information.

Generally, the classical *additional singleton task* paradigm (Theeuwes, 1991; Theeuwes, 1992), which is typically employed to investigate attentional capture, provided measures of this effect by averaging performance within a whole session, without considering the possibility that it might change over time. For this reason, to better monitor any fluctuation of the availability of attentional resources over time, we decided to analyze the entire timeline of the experimental session, dividing it in consecutive blocks.

Unfortunately, differently from what we expected, we could not observe any signs of depletion of the attentional resources during the experimental session, because the cost associated with distractor presence, our main index of attentional engagement, appeared – if anything – to become lower, instead of higher, across consecutive blocks. So, despite all the manipulations applied in order to pose great stress and overload on attentional processing, performance seemed to improve during the session, perhaps due to the effects of practice with the overall task and with the attentional mechanisms involved in target selection and distractor filtering. Previous studies have suggested in fact that under normal conditions attentional mechanisms can learn to become less sensitive to the presence of frequent distractors that seem to lose progressively their attractive power (Kelley & Yantis, 2009; Turatto & Pascucci, 2016).

Regarding the impact of emotional images, our results demonstrated that these stimuli exerted a detrimental influence on attentional processing, with greater costs in performance associated with images with a negative emotional content. However, it is possible that throughout the session, while subjects became more experienced with the task and "learned" to manage the emotional responses that they engendered, the overall effect due to these images might have become progressively lower. Overall responses in trials comprising the display of emotional images led to faster but less accurate responses, maybe because their intrinsic arousing value induced a stronger autonomic response in participants (Buodo, et al., 2002; Schimmack, 2005; Mogg, et al. 2000). Importantly, while this arousing effect in RTs was overall higher for images with positive valence compared to the negative ones, negative images seemed to affect more specifically attentional filtering mechanisms, showing a tendency to modulate significantly the attentional capture effect. At any rate, both effects were rather weak, and seemed to become even weaker towards the end of the experimental session.

Indeed, it is possible that, given the repeated exposure of the emotional images (each was repeated four times during the session), subjects might have become familiar with their content, and this could have contributed to a fading of their arousing effects over time.

Another complexity arose from the fact that all images were intermixed during the session, with negative and positive images randomly interleaved. It could be therefore hypothesized that if any detrimental effect were triggered by negative images, the subsequent processing of an image with an opposite valence might have helped “restore” any disruption, and/or vice-versa (Helton & Russell, 2011, Ossowski, et al., 2011), leading to a general confound in the modulations to be observed in overall performance and in attentional filtering. Several studies in fact have proved marked benefits in attentional and memory functions and, more generally, in cognitive control after brief interactions with natural scenarios (Berman, et al., 2008; Berto, 2005; Cimprich & Ronis, 2003; Faber, Taylor, Kuo, & Sullivan, 2002; Hartig et al., 2003; Tennessen & Cimprich, 1995). Indeed, many images with positive valence in our sample depicted such kind of natural scenes, therefore it is very likely that whenever they appeared on the screen they might have counteracted any effect of depletion or fatigue, hindering the possibility of finding any decrease in performance over time (Laumann, et al., 2003).

To overcome this possible issue, we set out a second experiment, in order to explore more systematically the impact of emotional images on the working of attentional mechanisms. Experiment 2 employed a between-subjects design and comprised three groups of participants, each performing a variation of the same experimental task, which was identical to the one adopted in Experiment 1. In order to verify whether the random interleaving of images with opposite emotional valences could be a real opponent to depletion of attentional resources, we applied a new manipulation. In each of the three following experiments, the 80% of trials containing images was characterized by a specific valence for the whole experimental session, namely, positive, negative and neutral, which acted as a control condition.

Chapter 7

The impact of emotional stressors on distractor filtering

7.1 Experiment 2

The evidence collected in Experiment 1 suggested that, differently from what we expected, attentional resources could not be depleted over time.

However, as discussed above, such failure might have been caused by some of the methodological choices made when designing the study. Two main issues might have had a detrimental role on our experimental design. Firstly, participants might have developed familiarity with the emotional images delivered during the experiment. In fact, only a relatively small number of images was selected from the International Affective Picture System (IAPS) Catalogue to be used as emotional stimuli, specifically 192 images with negative valence and 192 with positive valence. Because of their limited number with respect to the number of trials in the session, each image was repeated four times during the experimental session. Previous research has shown that even stimuli that are able to trigger powerful emotional responses when they are first perceived, gradually lose their arousing value after repeated exposures (Codisposti et al., 2006; Zald, 2002). It is possible therefore that the arousing and attention-grabbing power of our emotional images faded over time, reducing at the same time the effort needed to filter out their distracting content. Secondly, positive and negative images were presented in a random order. As explained above, it is possible that any detrimental effect triggered by images with negative valence (which seemed to determine the largest costs in subsequent attentional performance), might have been counteracted by the succeeding processing of an image with opposite, pleasant valence, that might have helped in "restoring" any disruption (Berman, et al., 2008; Berto, 2005; Cimprich & Ronis, 2003; Faber, Taylor, Kuo, & Sullivan, 2002; Hartig et al., 2003; Tennessen & Cimprich, 1995).

In order to overcome these possible weaknesses of our first study, we designed a new experiment. Again, the aim was that of investigating the possibility that attentional resources could be depleted by means of a speeded and attentionally demanding attentional task, by displaying non-relevant, but emotionally charged, images at the start of each trial. In this case however two main variations were introduced with respect to the methods adopted in Experiment 1. On the one hand the emotional valence of the images displayed on each trial was manipulated as a between-subjects factor, so that in each group all subjects were exposed to images with the same valence for the whole experiment. On the other, we increased the sample size of the emotional images, so that each of them was only used in one single trial. The visual search task was the same as described in Experiment 1. Three groups of participants were recruited, and each group was associated with the display of images with a different type of emotional valence: Neutral, Positive or Negative.

7.2 Materials and methods

Participants

Sixty-five participants took part in Experiment 2. Specifically, twenty-two participants (10 males; mean age ± SD, 23.31 ± 3.07) took part in the Neutral valence condition, twenty-one (10 males; mean age ± SD, 22.71 ± 2.17) in the Positive valence condition and twenty-two (12 males; mean age ± SD, 21.72 ± 1.90) in the Negative valence condition. Overall, five participants had to be excluded from the final sample. Three of them were excluded because they did not reach the accuracy threshold value of 75% and the other two because they abandoned the experiment before completing the whole experimental session. All subjects in the final sample (30 males; mean age ± SD, 22.68 ± 2.54; Neutral valence condition: 10 males; mean age ± SD, 23.5 ± 3.13; Positive valence condition: 9 males; mean age ± SD, 22.7 ± 2.22; Negative valence condition: 11 males; mean age ± SD, 21.85 ± 1.95) were right-handed and with normal or corrected-to-normal vision. Most of the participants were students at the University of Verona, Italy. None of them had previously taken part in similar or related studies, and they were all naive as to the purpose of the study. All the participants received fixed monetary compensation for their participation (15 euros) and gave written informed consent before participation. The protocol was approved by the Review Board for Studies involving Human Participants of the University of Verona, Italy.

Apparatus

This was identical to the one used for Experiment 1.

Design and procedure

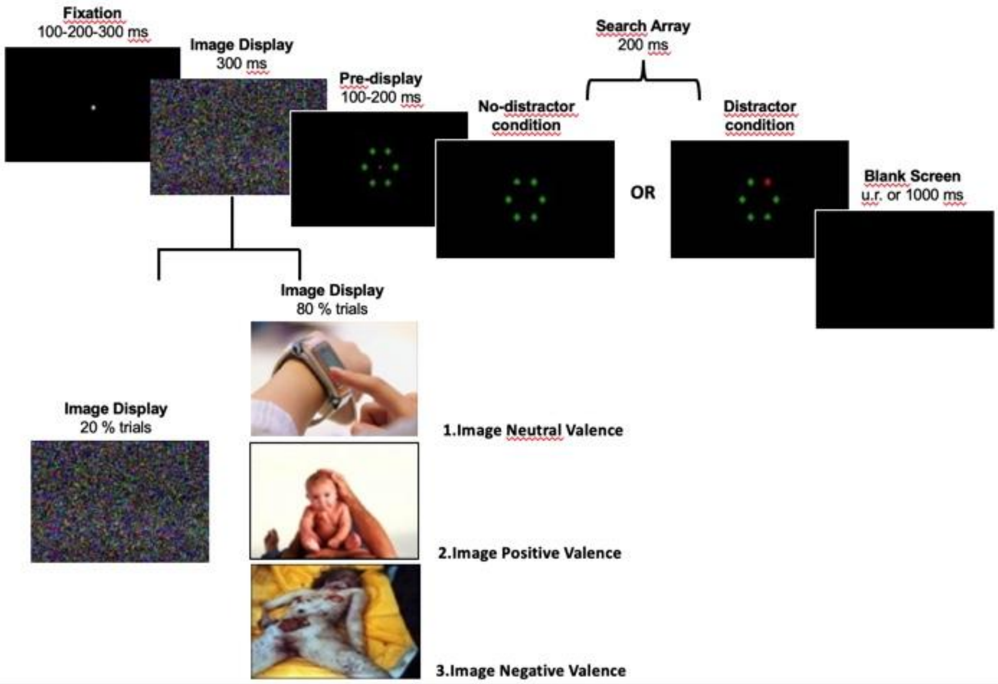


Fig.1 Graphic illustration of example trials for each of the three different emotional valence conditions.

Design and procedure were identical to those of Experiment 1, with the following exceptions.

Participants completed an initial practice block of 60 trials, followed by the Depletion block. The experimental session lasted approximately one hour and fifteen minutes and consisted of 1920 trials, of which 1536 (80%) were preceded by an image with emotional valence (Image present trials) and 384 (20%) trials were preceded by colored noise screen (Image absent trials). Image present and absent trials were presented in a random order (see Figure 1).

Three new sets of images were selected, 1536 for each level of emotional valence: Neutral, Positive or Negative. The emotional valence of the image shown at the start of each trial was manipulated as a between-subjects factor, so that each group of subjects was administered only one set. Images were chosen from International Affective Picture System (IAPS) Catalogue, Emotional Pictures Set (EmoPicS), Geneva Affective PicturE Database (GAPED), Nencki Affective Picture System (NAPS) Catalogues and from Google Images (Lang, et al., 2005; Wessa, et al. 2010; Marchewka et al., 2014; Riegel et al., 2016; Wierzba et al., 2015; Michalowsky et al., 2016; Dan-Glauser & Scherer, 2011).

Data analysis

This followed the same approach as used before. While emotional valence was manipulated across groups of subjects, each group performed the main task in trials in which the image was present (80%) and trials in which it was absent (20%). The task required to discriminate the target by reporting with a keypress the top-or bottom location of its base, and a salient distractor could be present or absent in the search array in 50% of cases.

In line with what we had done in the previous experiment, data analyses were initially performed on both mean RTs of correct responses and accuracy rates. A close inspection of the results however suggested that the effects of our crucial manipulations were to be found specifically in accuracy rates. For the present discussion we decided therefore to focus on the results obtained from this dependent variable. The results of the same analyses conducted on mean RTs are extensively reported in the Appendix 1 section A.

Results

Image present trials

The accuracy rate on the 80% of the trials in which the images were displayed were entered into a mixed effects ANOVA including Valence (neutral, positive and negative) as a between-subjects factor, and Distractor Presence (present or absent), Block (1-4), and Predisplay duration (100 or 200 ms) as within-subjects factors.

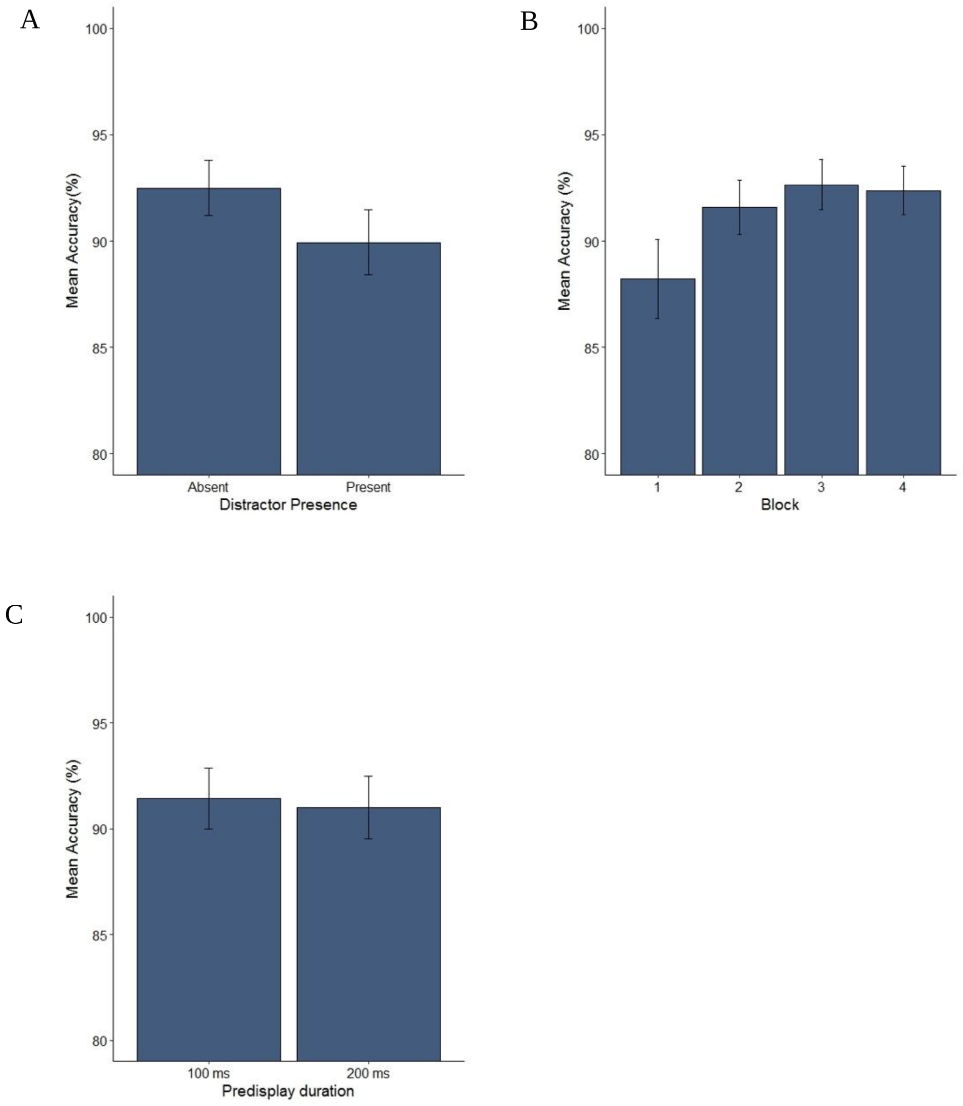


Fig.2 Image present trials analysis: Main effects. A. Main effect of Distractor Presence. B. Main effect of Block. C. Main effect of Predisplay duration.

The ANOVA revealed a main effect of Distractor Presence, $F_{(1,\ 57)} = 72.43$, $p < .001$, $\eta p2 = .559$, with lower accuracy in the Distractor-present condition compared to the Distractor-absent condition (89.93% vs 92.48%). The salient distractor interfered with the task at hand, reflecting the well-known attentional capture effect (Fig.2 panel a). The main effect of Block was also significant, $F_{(3,}$

$_{171)}$ = 24.65, p < .001, ηp2 = .411, revealing that accuracy increased towards the end of the session (Fig.2 panel c). The main effect of Predisplay duration was marginally significant, F$_{(1,\ 57)}$ =3.25, p = 0.07, ηp2 = .054 (Fig.2 panel c), with accuracy being overall higher with the shorter Predisplay duration (91.42 % vs 90.99 %) (Fig.2 panel c).

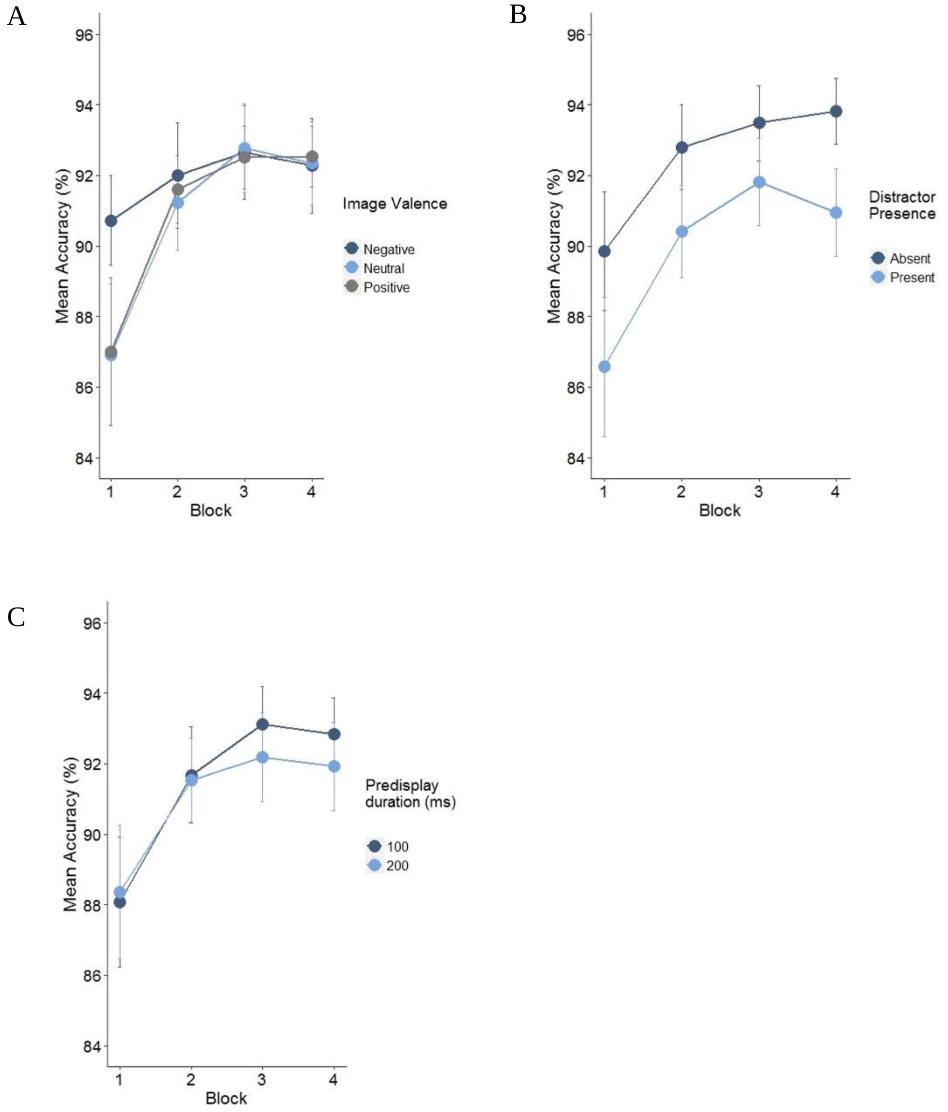


Fig.3 Image present trials analysis: Interactions between factors. A. Interaction Image Valence as function of Block. B. Interaction Block as function of Distractor Presence. C. Interaction Block as function of Predisplay duration.

Interestingly, although the main effect of Valence was far from being significant ($F_{(2, 57)} = 0.33$, $p = 0.71$), the interaction between Valence and Block was significant, $F_{(6, 171)} = 2.23$, $p = 0.04$, ηp2 = .055 (Fig.3 panel a), suggesting that although the accuracy in all of the three groups improved across consecutive blocks (mean acc by Block; Neutral Valence by Block 1 = 86.96, Block 2 = 91.12, Block 3 = 92.73, Block 4 = 92.26; Positive Valence by Block 1 = 86.97, Block 2 = 91.62, Block 3 = 92.40, Block 4 = 92.42; Negative Valence by Block 1 = 90.76, Block 2 = 91.94, Block 3 = 92.64, Block 4 = 92.19), this effect was more marked for the groups with Neutral and Positive Valence images, whose accuracy was significantly lower in the first block, compared to the Negative valence group. In the second block the accuracy of the group with Neutral images was still significantly lower than the other two, while all groups reached a similar performance level afterwards (Neutral Valence by Block 1 vs. Block 2: $t_{(19)} = -4.05$, $p = 0.002$; by Block 2 vs. Block 3: $t_{(19)} = -2.37$, $p = 0.05$; by Block 3 vs. Block 4: $t_{(19)} = 0.96$, $p = 0.348$; Positive Valence by Block 1 vs. Block 2: $t_{(19)} = -3.17$, $p = 0.04$; by Block 2 vs. Block 3: $t_{(19)} = -1.74$, $p = 0.7$; by Block 3 vs. Block 4: $t_{(19)} = -0.04$, $p = 1$; Negative Valence by Block 1 vs. Block 2: $t_{(19)} = -1.73$, $p = 0.295$; by Block 2 vs. Block 3: $t_{(19)} = -1.51$, $p = 0.295$; by Block 3 vs. Block 4: $t_{(19)} = 1.08$, $p = 0.295$) (Fig.3 panel a). The interaction between Block and Distractor was also significant, $F_{(3, 171)} = 2.75$, $p = 0.04$, ηp2 = .172 (Fig.3 panel b). Accuracy was higher in the Distractor-absent condition compared to Distractor-present condition and this effect was significant in all of the four Blocks (Distractor-absent vs. Distractor-present by Block 1: $t_{(59)} = 5.55$, $p < .001$; Distractor-absent vs. Distractor-present by Block 2: $t_{(59)} = 5.06$, $p < .001$; Distractor-absent vs. Distractor-present by Block 3: $t_{(59)} = 4.04$, $p < .001$; Distractor-absent vs. Distractor-present by Block 4: $t_{(59)} = 7.70$, $p < .001$). However, the cost associated with distractor presence was significantly different between Blocks. In fact, it was observed a significant increase only between Block 3 and 4 (Difference in cost of Distractor by Block 1 vs. Block 2: 3.26 vs. 2.39, $t_{(119)} = 1.45$, $p = 0.14$, by Block 2 vs. Block 3: 2.39 vs. 1.67, $t_{(119)} = 1.39$, $p = 0.16$, by Block 3 vs. Block 4: 1.67 vs. 2.87, $t_{(119)} = -2.58$, $p = 0.01$), reflecting an increase in the cost of distractor in the last block. The interaction between Block and Predisplay duration was marginally significant, $F_{(3,\ 171)} = 2.38$, $p = 0.07$, ηp2 = .099, suggesting that, as can be appreciated in Fig.3 panel c, the difference between the two Predisplay conditions tended to grow throughout the session.

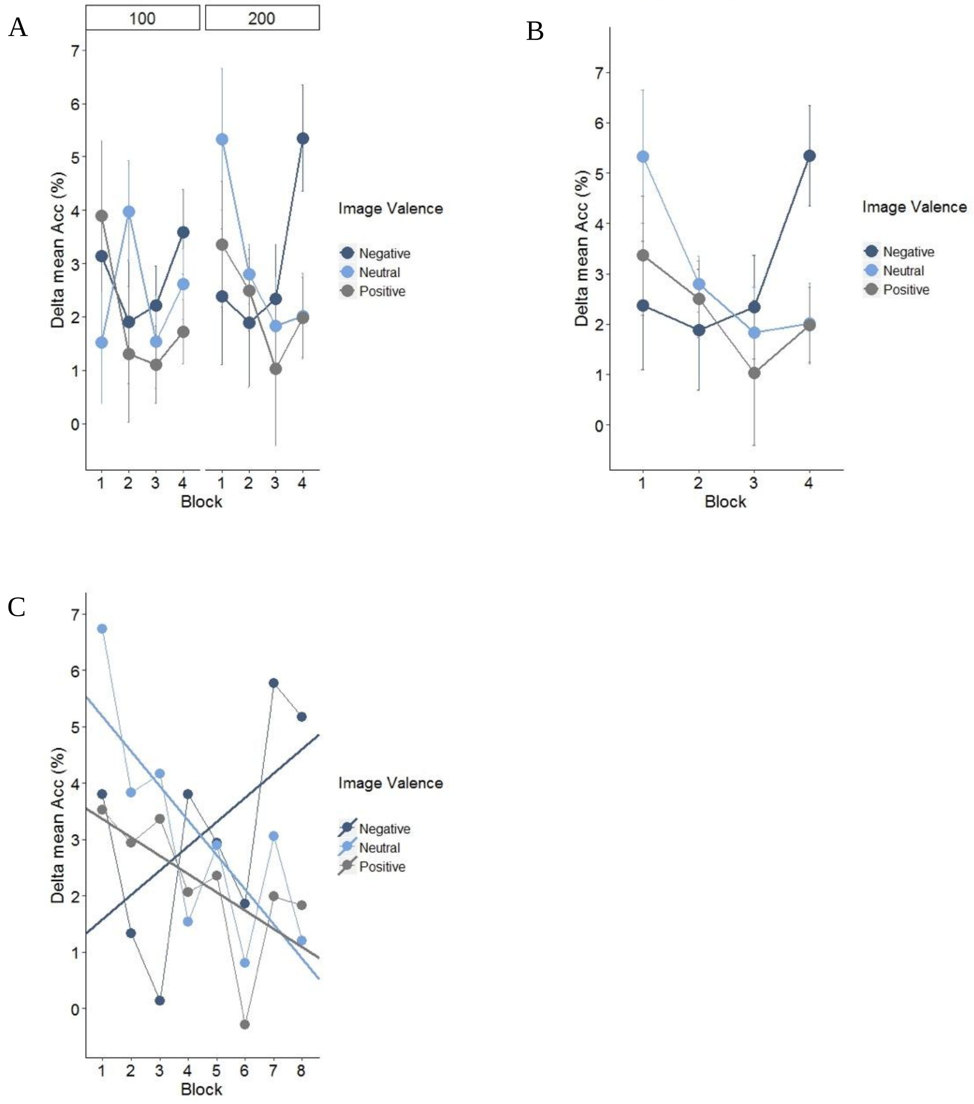


Fig.4 Image present trials analysis: Interactions between factors. A. Cost of Distractor as function of Block, Image Valence and Predisplay duration. B. Cost of Distractor as function of Block and Image Valence. C. Linear regression analysis of cost of Distractor as function of Block and Image Valence.

Interestingly, the 4-way interaction between Valence, Distractor, Block and Predisplay duration was significant, $F_{(6,\ 171)} = 2.15$, $p = 0.04$, ηp2 = .091 (Fig.4 panel a). To better understand this interaction, we performed two separate ANOVAs, analyzing separately trials with different Predisplay durations. In these analyses we focused on the three-way interactions between Valence, Distractor and Block, which was crucially in line with the aim of unveiling whether as the session proceeded, the presence of an irrelevant, but emotionally charged image, would reduce the efficiency of the attentional mechanisms involved in the filtering of distractors. Interestingly, this triple interaction approached significance in the condition of Predisplay duration of 200 ms, $F_{(6,\ 171)} = 2.10$ $p = 0.05$, ηp2 = .085 whereas, in trials with a Predisplay duration of 100 ms, it was rather far from being statistically significant, $F_{(6,\ 171)} = 1.66$ $p = 0.13$.

Given the considerable importance of this interaction with respect to our aims of research, we decided to assess more directly this effect by taking into account the distractor cost, namely, the difference in accuracy between distractor-present and distractor-absent condition.

Interestingly, the cost increased across blocks only in the Negative Valence group (Cost of distractor of Negative Valence by Block 1 = 2.37, Block 2 = 1.88, Block 3 = 2.33, Block 4 = 5.34; Difference in Cost of distractor of Negative Valence by Block 1 vs. Block 4 = 2.97, $t_{(19)} = -1.75$, $p = 0.09$). The increment in cost from Block 1 to Block 4 was around 3%, and was significantly greater than what could be observed both in the group with Positive valence images (Difference in Cost of distractor of Negative Valence vs. Positive Valence by Block 1 vs. Block 4: $t_{(19)} = -2.14$, $p = 0.04$) and in the group with Neutral valence images (Difference in Cost of distractor of Negative Valence vs. Neutral Valence by Block 1 vs. Block 4: $t_{(19)} = -2.57$, $p = 0.01$). Indeed in the latter groups the cost tended to decrease across blocks, showing a trend that was exactly opposite (Cost of distractor of Positive Valence by Block 1 = 3.36, Block 2 = 2.49, Block 3 = 1.02, Block 4 = 1.98; Difference in Cost of distractor of Positive Valence by Block 1 vs. Block 4 = -1.38; Cost of distractor of Neutral Valence by Block 1 = 5.33, Block 2 = 2.80, Block 3 = 1.83, Block 4 = 2.01; Difference in Cost of distractor of Neutral

Valence by Block 1 vs. Block 4 = -3.32; Difference in Cost of distractor of Positive Valence vs. Neutral Valence by Block 1 vs. Block 4: $t_{(19)} = 1.07$, $p = 0.29$)(Fig.4 panel b). In order to conduct a more fine-grained analysis of Block-dependent variations in distractor costs, we divided each session in eight subsequent blocks, and – separately for each group – performed a linear regression analysis, on cost as a function of Block (Fig 4 panel C). All the linear regressions were not significant (Negative: $F_{(1, 6)} = 0.18$ $p = 0.68$, adj-$r^2 = -0.13$; Positive: $F_{(1, 6)} = 4.81$ $p = 0.07$, adj-$r^2 = 0.35$; Neutral: $F_{(1, 6)} = 4.25$ $p = 0.08$, adj-$r^2 = 0.31$), however while in the negative valence condition the trend was towards an increase across blocks, the cost tended to decrease significantly in both Neutral and Positive conditions. Post-hoc comparisons between the regression coefficients associated with each group highlighted the fact that the trend observed in the group with negative valence images was significantly different from the other two (Slope Coefficient of Negative Valence vs. Positive Valence: $t_{(19)} = 2.36$, $p = 0.02$; Negative Valence vs. Neutral Valence: $t_{(19)} = 2.93$, $p = 0.008$; Positive Valence vs. Neutral Valence: $t_{(19)} = 0.96$, $p = 0.34$).

Image absent trials

A separate ANOVA was performed on the remaining 20% of trials in which, instead of images with emotional content, a colored noise image was displayed full screen. Interestingly, this condition was identical for all groups, the only difference being the general emotional context triggered by the images shown in the other trials. The factors considered were Valence (neutral, positive and negative) as the between-subjects factor, Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 200 ms) as within-subjects factors.

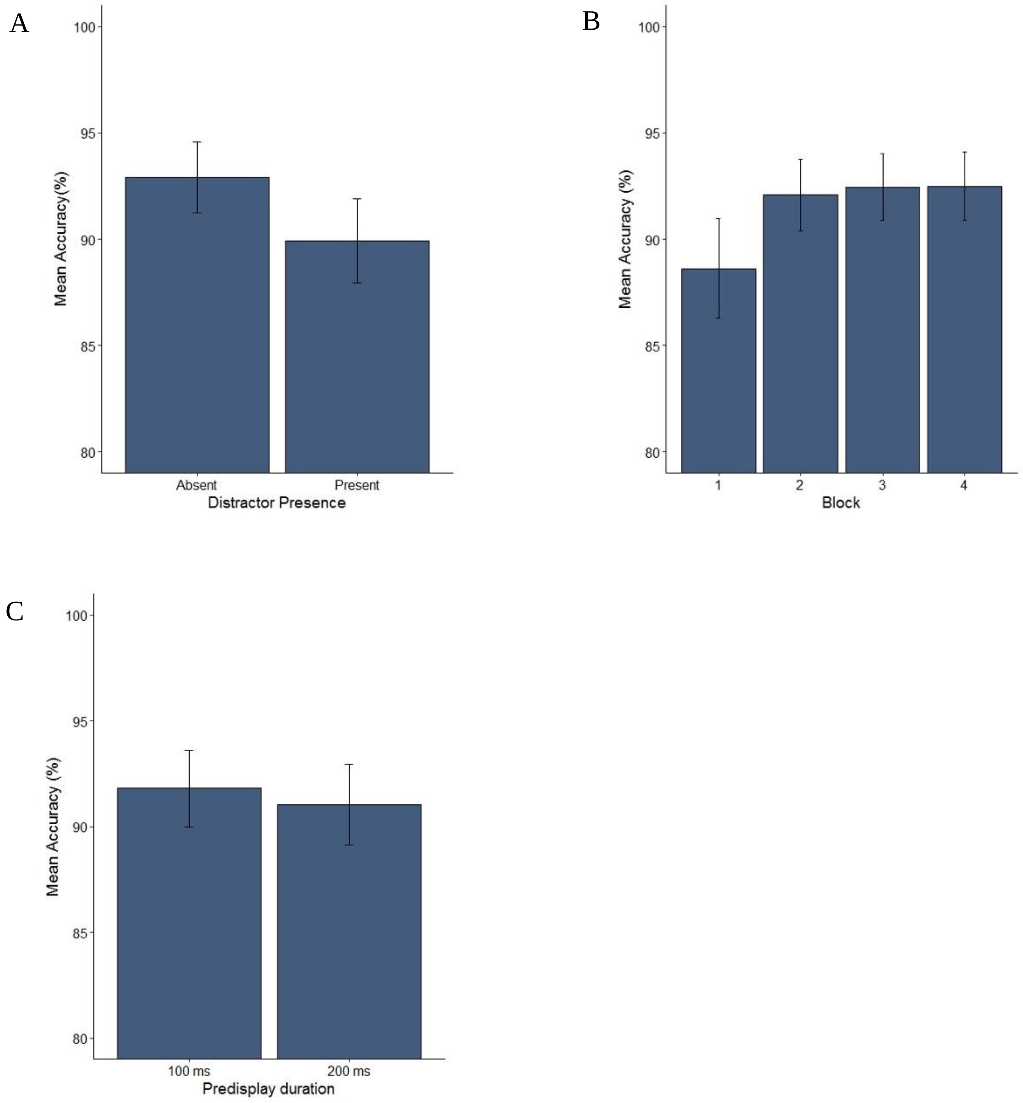


Fig.5 Image absent trials analysis: Main effects. A. Main effect of Distractor Presence. B. Main effect of Block. C. Main effect of Predisplay duration.

The results revealed significant main effects of Distractor Presence, $F_{(1, 57)} = 50.44$ $p < .001$, ηp2 = .469 (Fig.5 panel a), and Block, $F_{(3, 171)} = 10.65$ $p < .001$, ηp2 = .252 (Fig.5 panel b), which were consistent with those obtained in the analysis of responses to image present trials. The effect of Predisplay duration was only marginally significant, $F_{(1, 57)} = 3.00$ p = 0.08, ηp2 = .051 (Fig.5 panel c).

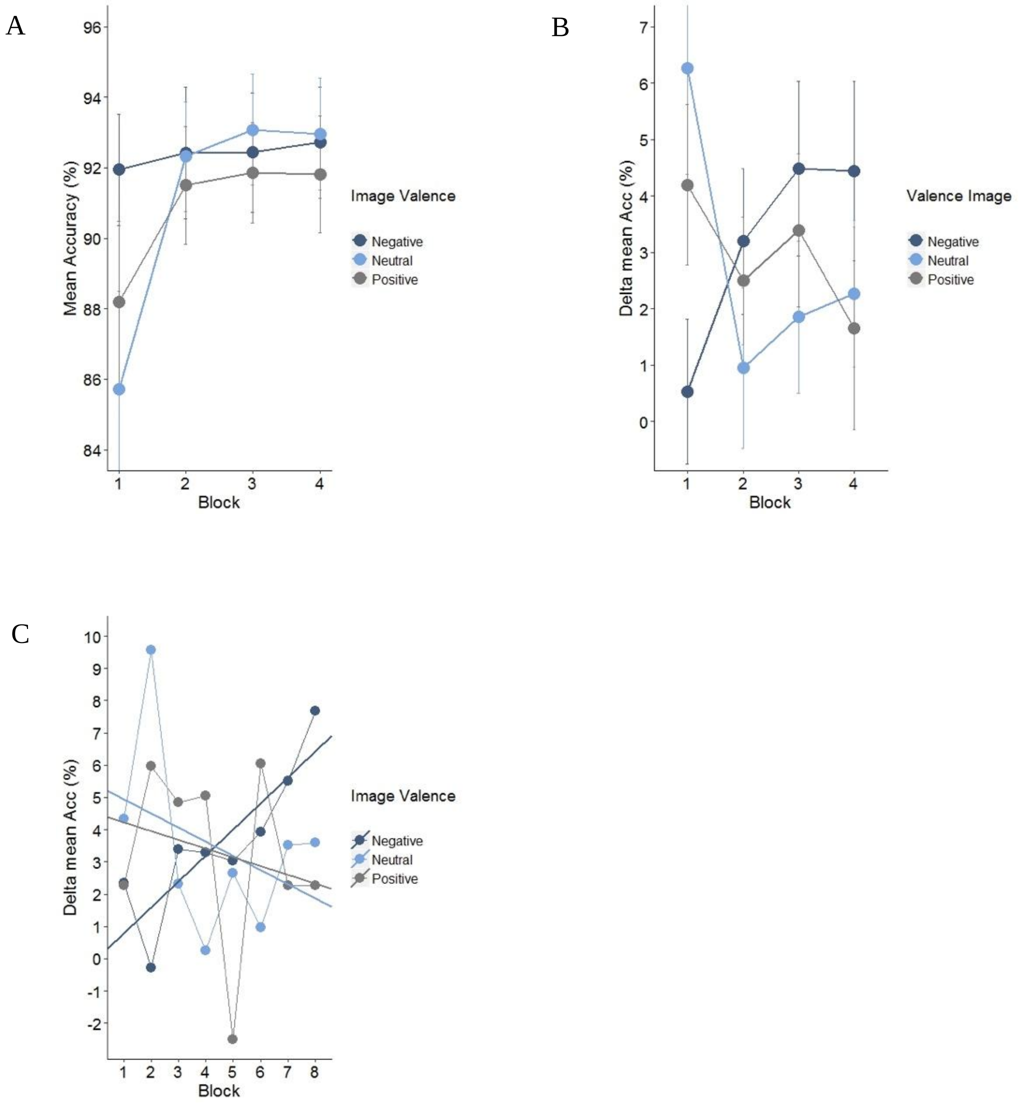


Fig.6 Image absent trials analysis: Interactions between factors. A. Interaction Block as function of Image Valence. B. Cost of Distractor as function of Block and Image Valence. C. Linear regression analysis of cost of Distractor as function of Block and Image Valence.

The interaction between Valence and Block was significant, $F_{(6,\ 171)} = 2.68$, $p = 0.01$, ηp2 = .076, and this effect was due to the fact that, in line with the previous results, the improvement by block over time was stronger for the Positive and Neutral Valence groups (Neutral Valence by Block 1 = 85.88, Block 2 = 92.24, Block 3 = 93.12, Block 4 = 92.75; Positive Valence by Block 1 = 88.14, Block 2 = 91.24, Block 3 = 91.90, Block 4 = 91.77; Negative Valence by Block 1 = 92.02, Block 2 = 92.08, Block 3 = 92.51, Block 4 = 92.63), whose accuracy in Block 1 was significantly lower with respect to the Negative valence group (Neutral Valence by Block 1 vs. Block 2: $t_{(19)}$ = -4.40, $p < .001$; by Block 2 vs. Block 3: $t_{(19)}$ = -0.96, p = 0.69; by Block 3 vs. Block 4: $t_{(19)}$ = 0.36, p = 0.71; Positive Valence by Block 1 vs. Block 2: $t_{(19)}$ = -2.05, p = 0.16; by Block 2 vs. Block 3: $t_{(19)}$ = -0.62, p = 1; by Block 3 vs. Block 4: $t_{(19)}$ = 0.10, p = 1; Negative Valence by Block 1 vs. Block 2: $t_{(19)}$ = -0.05, p = 1; by Block 2 vs. Block 3: $t_{(19)}$ = -0.41, p = 1; by Block 3 vs. Block 4: $t_{(19)}$ = -0.15, p = 1) (Fig.6 panel a). Interestingly, a three-way interaction of Valence by Distractor by Block was very close to statistical significance, $F_{(6,\ 171)}$ = 2.09, p = 0.056, ηp2 = .096. Again, taking into account the cost associated with the distractor, an increase was found in the cost across blocks, but only for the group with Negative Valence images (Negative valence: Block 1 = 0.52, Block 2 = 3.19, Block 3 = 4.48, Block 4 = 4.43; Block 1 vs. Block 4 = 3.91,$t_{(39)}$ = -1.97, p = 0.05) while for both the groups with Neutral and Positive Valence images the cost tended to decrease across blocks (Positive Valence: Block 1 = 4.19, Block 2 = 2.49, Block 3 = 3.39, Block 4 = 1.65; Block 1 vs. Block 4 = -2.54; Neutral Valence: Block 1 = 6.26, Block 2 = 0.94, Block 3 = 1.85, Block 4 = 2.27; Block 1 vs. Block 4 = -3.99)(Fig.6 panel b). In line with the approach adopted with respect to the trials in which an image was present, we performed separate linear regression analyses on costs by Block in the three groups, focusing on trials with a Predisplay duration of 200 ms. Although the overall trend was very similar to what observed in the previous analysis, on image present trials, none of these analyses reached statistical significance. The post-hoc t-test, run to investigate whether the linear coefficients of the three regression lines were reliably different, were all non-significant (Fig. 6 panel c).

7.3 Discussion

In this Experiment, the main effects of our manipulations were crucially revealed by error rates, as the same analyses performed on RTs of correct responses led to mainly non-significant results (see Appendix). This might have been due to the fact that the paradigm required speeded responses, allowing a very short deadline for response delivery. Such fast and forced response pace might in fact have limited the possibility of observing effects associated with the crucial manipulations in RTs. As a matter of fact, the only significant effect emerging in RTs was a generalized improvement of performance across blocks, with responses becoming faster towards the end of the session (see Appendix). On the other hand, the need to respond very quickly led to an overall significant fraction of error trials, with the error rate being significantly affected by the experimental manipulations.

As in Experiment 1, our paradigm proved to be suitable for measuring attentional capture in all of the three groups. Indeed, capture of exogenous attention by the salient distractor caused disruption in the ongoing task, and a decrease in performance was systematically observed in the distractor-present condition compared to the distractor-absent condition.

As already discussed, in Experiment 1 we failed to observe any sign of depletion during the experimental session, since the costs associated with distractor suppression, both in RTs and in error rates, tended to become smaller (instead of larger) towards the end of the experimental session. In line with our hypothesis, if it was possible to deplete specifically the cognitive resources associated with selective attention, one should expect that the more the resources become depleted with the ongoing task, the higher should become the cost due to the need to filter out salient distractors. In that case however we reasoned that two aspects of the adopted paradigm might have prevented the depletion of attentional resources. On the one hand, the repetition of the emotional images during the session might have increased their familiarity and reduced their arousing value, leading to lower interference with the main task. On the other, the use of images with different emotional valence, and possibly different impact on attentional processes, might have led to confounds in the observed effects, as described above in the Introduction. Therefore, in this experiment, we adopted a large sample of new images arranged according to their valence and administered them separately to different groups of subjects. Comparing performance across groups allowed us to observe crucial differences associated with the delivery of irrelevant images with a different emotional valence.

Indeed, the results of Experiment 2 suggested that the attentional mechanisms involved in distraction filtering were affected by the different emotional content of the images. In particular, Negative and Positive images had an opposite effect on the ongoing attentional processing, with intermediate – virtually null – effects associated with Neutral images (Fig.4 panel a). Up to now, there is substantial amount of support for the claim that emotional information, even if it is task-irrelevant, can capture attention disrupting task performance (Hodsoll, et al., 2011; Yiend, 2010). Moreover, many studies have also demonstrated that emotional stimuli are processed faster and modulate the processing of other concomitant stimuli (Dijksterhuis & Aarts, 2003; Eastwood et al., 2001; Eimer & Holmes, 2002; Globish, et al., 1999; Krolak-Salmon et al., 2006). However, it is still debated whether their processing is automatic, and therefore systematically prioritized, or depends on the availability of attentional resources, and therefore can occur only under certain conditions (Pessoa, 2005; Pessoa, et al., 2002; Vuilleumier, 2005; Vuilleumier et al., 2001). In line with this literature, with Experiment 2 we demonstrated that task-irrelevant images with an emotional content indeed exerted a detrimental influence on attentional processing, with greater costs in performance associated with images with negative valence. Accordingly, many studies have shown that negative stimuli elicit more rapid and more prominent responses than do positive or neutral ones (Armony & Dolan, 2002; Erthal, et al., 2005; Pessoa, et al., 2005; Anderson, et al., 2003; Mogg & Bradley, 1998; Mogg et al., 2000; Baumeister, et al., 2001; Cacioppo & Gardner, 1999; Taylor, 1991). Most theorists agree that the bias towards negative information originates from a purely evolutionary perspective according to which negative stimuli signal danger and, hence, must be processed quickly, allowing for the execution of an appropriate behavioural response. In addition, it has been shown that negative emotional stimuli compete heavily for attentional resources as they appear to capture and retain attention (Kern et al., 2005, Helton et al., 2011). In line with this literature, with our first between-subjects analysis, carried out on the trials preceded by task-irrelevant but emotionally charged images (80%

of trials), we could assist to a depletion of attentional resources in a very short period of time, i.e. one-hour session, in the group with negative valence images. In fact, we found a substantial reduction in distractor filtering efficiency throughout the experimental session only in the negative group, where the cost associated with attentional capture by the salient distractor in the search display increased significantly. On the other hand, an improvement in performance was registered in the groups to which positive or neutral images were shown at the start of each trial (Fig.4 panel b). Here the cost due to distractor filtering tended to decrease within the session. Previous studies have shown that the attentional system can learn to become less sensitive to the presence of frequent distractors over time and, therefore, such improvement suggested that the delivery of positive and neutral emotional images did not interfere with the beneficial effects of attentional learning (Kelley & Yantis, 2009; Turatto & Pascucci, 2016). The reduction in the attentional capture cost was especially evident in the group with positive images. This result could perhaps be expected since it is known that marked overall benefits can be observed in cognitive and attentional control processes after brief interactions with scenes depicting natural environments, and many of the positive images in our sample represented natural scenes (Berman, et al., 2008; Berto, 2005; Cimprich & Ronis, 2003; Faber, Taylor, Kuo, & Sullivan, 2002; Hartig et al., 2003; Tennessen & Cimprich, 1995).

It is of particular importance to notice that similar results were found in the analysis performed on responses to trials that were not preceded by images with an emotional content (20% of trials). Hence, even when no image was shown prior to the search display, the cost associated with distractor filtering tended to increase across the session in the group that was exposed to negative valence images compared to the other two. This finding suggests that the prolonged exposure to emotional stimuli over the experimental session produced an emotional context effect, which extended and amplified the impact of the emotional images shown. Altogether, these results provide a unique evidence of how images with emotional content might interfere with the working of attentional mechanisms and induce a systematic depletion of attentional resources over time.

In conclusion, differently from Experiment 1, in Experiment 2 we could demonstrate a depletion of attentional resources under condition of very heavy and persistent taxing of attentional processing in a very short period of time, i.e. one-hour session. Moreover, our results revealed that emotional stimuli with a negative valence, even if task-irrelevant, can be considered as powerful stressors for the attentional system, impairing not only the ability of an individual to resist distraction per se, but also to recover the efficiency of attentional processing resources over time on a trial by trial basis, leading to the depletion of such resources.

Importantly, all of these effects emerged remarkably in trials with a longer Predisplay duration. This interval consisted of a blank period intervening between the offset of the emotional image and the onset of the display comprising the task-relevant stimuli. Hence, the impact of (negative) emotional images on attentional deployment and the depletion of attentional resources was maximum when more time was allowed for the lingering processing of emotional information. These could therefore be analyzed more deeply, determining a more widespread engagement of different brain systems, specifically involving the processing of their semantic and arousing contents.

Since the present findings do suggest that the processing of task-irrelevant negative stimuli can disrupt overall target selection and distraction filtering, we aimed at investigating whether such effects can vary according to the degree to which the processing of the emotional contents of the stimuli is allowed by the experimental context. Indeed, if the detrimental effects on attentional processing are due to the fact that negative stimuli access higher-level processing automatically, one could expect that irrespectively of all other factors, the presence of such stimuli during task performance will exert the same effects. On the other, if the attentional priority of negative images depends on the availability of cognitive resources and is affected by top-down signals, one might expect that by manipulating the task requirements relative to these images it will be possible also to vary their impact on the concomitant attentional task.

We decided to explore more systematically these possibilities by setting out two further experiments. These aimed on the one hand to replicate the general context of the Negative image condition of Experiment 2, but on the other to either increase or reduce the degree to which the systematic processing of the negative images was allowed during the course of the experiment. Specifically, in Experiment 3 we wanted to reduce the impact of the images with negative valence, by engaging subjects on a secondary task which was to be carried out in parallel to the main visual search task. The need to divide processing resources between two tasks, both relevant for the experiment, might have left less chances for an automatic processing of the emotional content in the pictures, limiting therefore its impact on performance. Conversely, in Experiment 4 we wanted to emphasize the emotional response that could be generated after the presentation of each image by introducing a Mood Induction Procedure before the start of the experimental session, which is thought to enhance the processing of emotional contents even when they are task-irrelevant (Gilet, 2008).

Chapter 8

Reducing the detrimental effect of negative emotional stimuli

8.1 Experiment 3

The results of Experiment 2 provided a clear evidence that when confronted with heavy and persistent distraction the resources needed for attentional filtering may become depleted, and this occurs within a relatively short period of time, i.e. one-hour. Indeed, the extra load on attentional selection was elicited by the display of images with emotional content, which interfered heavily with attentional mechanisms, even when they were completely irrelevant for the task at hand. In particular, this effect was crucially linked to images with negative valence, adding to the growing literature indicating that, among emotional stimuli, those with a negative valence compete more strongly for attentional resources, being able to attract and retain attention more efficiently (Hodsoll, et al., 2011; Yiend, 2010; Anderson & Phelps, 2001; Keil & Ihssen, 2004; Ohman et al., 2001; Zeelenberg et al., 2006; Kern et al., 2005, Helton et al., 2011).

Based on this literature, and on our initial findings, we hypothesized that, by manipulating the degree to which emotional stimuli were able to engage attentional resources, one might be able to observe differences in task performance, which would reflect not only a different overall impact on attentional selection per se, but also on the depletion of attentional resources during the experimental session.

Interestingly, in Experiment 2, the largest effects of our manipulations were obtained in trials with a longer Predisplay duration (i.e., 200 ms). In fact, as discussed previously, it was found that images with negative emotional content exerted a stronger impact on the deployment of attention, thus leading to depletion of attentional resources when more time was allowed for the lingering processing of emotional information.

In addition, it has been demonstrated that negative stimuli might also alter subjective mood, inducing conscious task-unrelated thoughts that require further attentional resources and determine a subsequent performance cost (Smallwood, et al., 2009, Smallwood, 2010). Given these premises, we hypothesized that the longer was the time allowed to process the images prior to the display of the task-relevant stimuli, the heavier should be their impact on attentional resources. For these reasons in Experiment 3 we decided to use only emotional images with a negative valence, and increase the duration of the longer Predisplay in our paradigm, bringing it to 400 ms, in order to create in this experimental condition a larger temporal gap from the view of the image to the onset of the stimuli, and allowing a greater opportunity for the emotional content of the images to exert their influence on attentional mechanisms and determine a greater consumption of attentional resources.

Having said this, with Experiment 3 we wanted to test more specifically whether it was possible to manipulate the impact exerted by images with negative emotional content on attentional mechanisms, in particular by reducing their disruptive effects.

To this aim, another manipulation was applied on the original paradigm used in the previous experiments. Participants performed the same visual search task of Experiment 2. In addition, however, they were required to perform a secondary task that involved the emotional images, which therefore ceased to be task-irrelevant. Such secondary task however was designed in order to push subjects to process the pictures with regard to a non-emotional feature, with respect to which their emotional content was completely irrelevant.

Participants in fact were asked to count the number of all the images in the session containing animals and, at the end of the session, to report this number to the experimenter.

8.2 Materials and methods

Participants

Twenty participants (11 males; mean age ± SD, 21.55 ± 1.64) took part in the Experiment. All subjects were right-handed and with normal or corrected-to-normal vision. Most of the participants were students at the University of Verona, Italy. None of them had previously taken part in similar or related studies, and they were all naive as to the purpose of the study. All the participants received fixed monetary compensation for their participation (15 euros) and gave written informed consent before participation. The protocol was approved by the Review Board for Studies involving Human Participants of the University of Verona, Italy.

Apparatus

This was identical to the one used for Experiment 1 and 2.

Design and procedure

Participants, as in the previous experiment, completed an initial practice block of 60 trials, followed by a single session for the experiment proper. The experimental session lasted approximately one hour and thirty minutes and consisted of 1920 trials.

Design and procedure were identical to those of Experiment 2 (negative valence condition), with the following exceptions.

The Predisplay duration could last 100 or 400 ms (as opposed to 100 and 200 ms), and a secondary task was carried out in parallel to the main visual search task. As anticipated above, participants were required to count and keep in mind the number of images containing animals over the experimental session and, at the end, to report this number to the experimenter. This task however was merely used as an experimental manipulation, and the number reported by subjects at the end of the session was not considered in data analysis.

Data analysis

This followed the same approach as used before. In line with what we had done in the previous experiment, data analyses were initially performed on both RTs and accuracy rates. However, since the effect of our crucial manipulation for this paradigm were better expressed by accuracy rates, for the present discussion we decided to mainly focus on accuracy rates results. The results of the same analyses conducted on mean RTs are extensively reported in the Appendix 1 section B.

Results

Image present trials

The data obtained in the 80% of trials, in which the images were displayed, were entered into a repeated measures ANOVA in which Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 400 ms) were within-subjects factors.

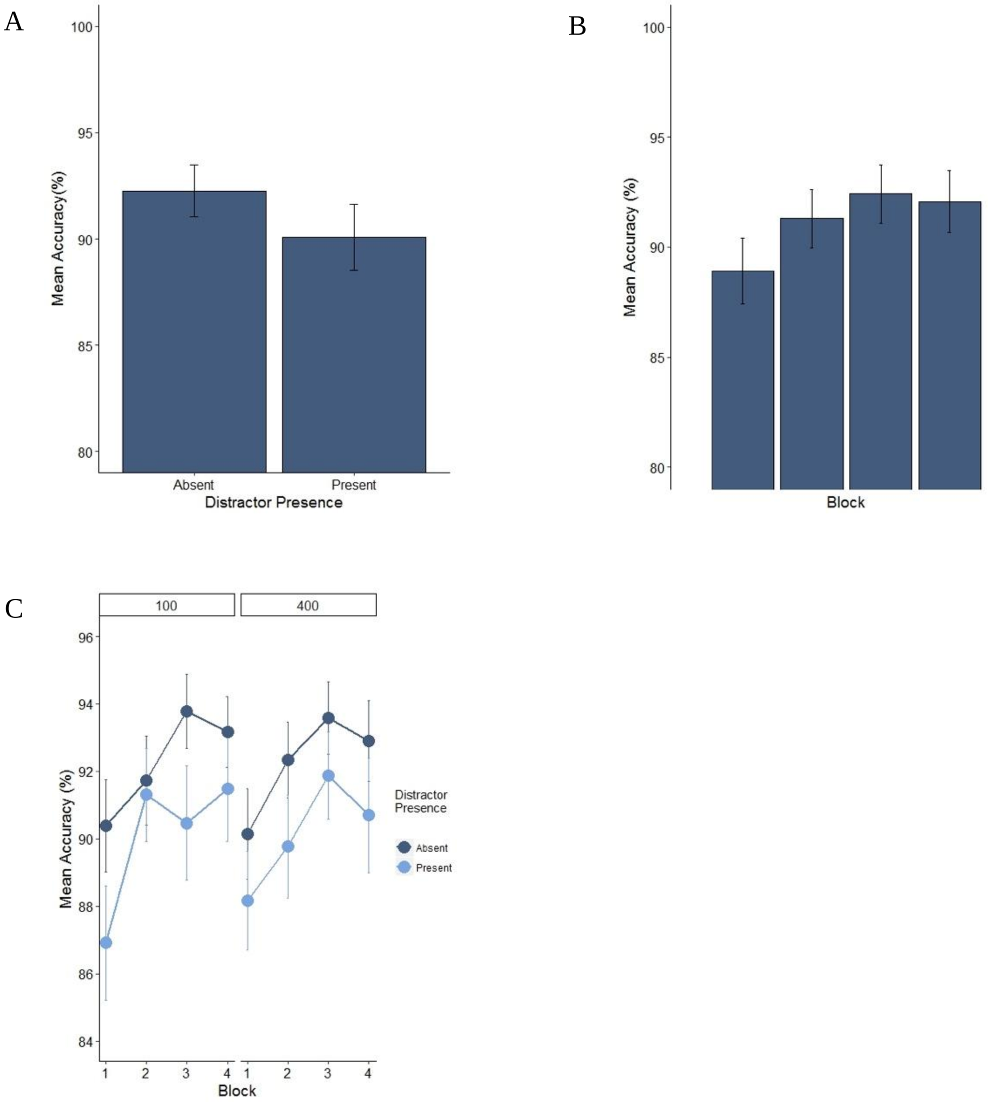


Fig.1 Image present trials analysis. A. Main effect of Distractor Presence. B. Main effect of Block. C. Interaction Distractor Presence as function of Block and Predisplay duration.

The ANOVA revealed a significant main effect of Distractor Presence, $F_{(1,\ 19)} = 17.38$, $p < .001$, ηp2 = .477, reflecting attentional capture, since in the condition Distractor-absent the accuracy was significantly higher compared to the Distractor-present condition (92.25 % vs 90.08 %) (Fig.1 panel a).

There was also an improvement in performance over time, supported by a significant main effect of Block, $F_{(3,\ 57)} = 6.91$, $p < .001$, ηp2 = .458 (Fig.1 panel b). Interestingly, neither the main effect of Predisplay ($F_{(1,\ 19)} = 0.004$, $p = 0.94$), or its interactions with Distractor presence ($F_{(1,\ 19)} = 0.051$, $p = 0.82$), nor Distractor presence and Block, reached significance, $F_{(3,\ 57)} = 2.08$, $p = 0.11$ (Fig.1 panel c). This result appears at first to contradict our experimental hypothesis that by increasing Predisplay duration we might have increased the impact of negative images on the depletion of attentional resources. As a matter of fact, performance to the main task appeared now rather insensitive to Predisplay duration.

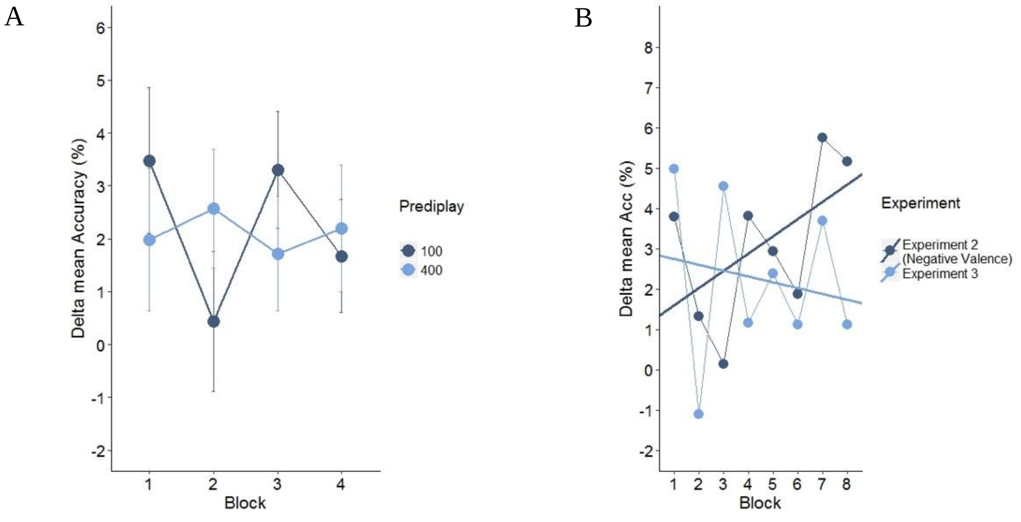


Fig.2 Image present trials analysis. A. Cost of Distractor as function of Block and Predisplay duration. B. Linear regression analysis of cost of Distractor as function of Block and Image Valence.

As we can clearly see from Fig.2 panel a, the cost of distractor in both conditions of Predisplay duration was constant over the experimental session. In order to better explore this negative result, we performed a linear regression analysis on the interaction of Distractor by Block, focusing in particular on the longer Predisplay duration (which in this Experiment was 400 ms), and compared these results with those obtained in the same analysis performed on the data obtained in Experiment 2 (Negative valence condition, longer Predisplay duration – 200 ms). The experimental session was divided into eight blocks to better capture any quantitative difference over time. The linear regression analysis on the data collected in the present Experiment was marginally significant, $F(1, 37) = 2.92$, $p = 0.09$, $\eta p2 = .071$ (Fig.2 panel b). With respect to Experiment 2, however, in which the trend reflected increasing cost due to distractor filtering over time, in the present experiment the data seemed to suggest an opposite tendency (direct comparison between the Slope Coefficients of Negative Valence Experiment 2 vs. Experiment 3: $t_{(19)} = -1.83$, $p = 0.08$).

Indeed, the secondary task introduced in this version of the paradigm seemed to have limited the detrimental effects on attentional resources that had emerged in Experiment 2. On the one hand, if the processing resources tapped by the secondary task were the same involved in the main task, we should have observed marked signs of resource depletion throughout the session. Since this was not the case, we must conclude that the secondary task hinged on processing resources - presumably associated with working memory and executive functioning - that are independent from visual selective attention. On the other hand, these results also suggest that the emotional contents of the images were less able to engage automatically visual selective attention, posed lower needs for attentional filtering, and consequently did not contribute to the depletion of the related processing resources.

Image absent trials

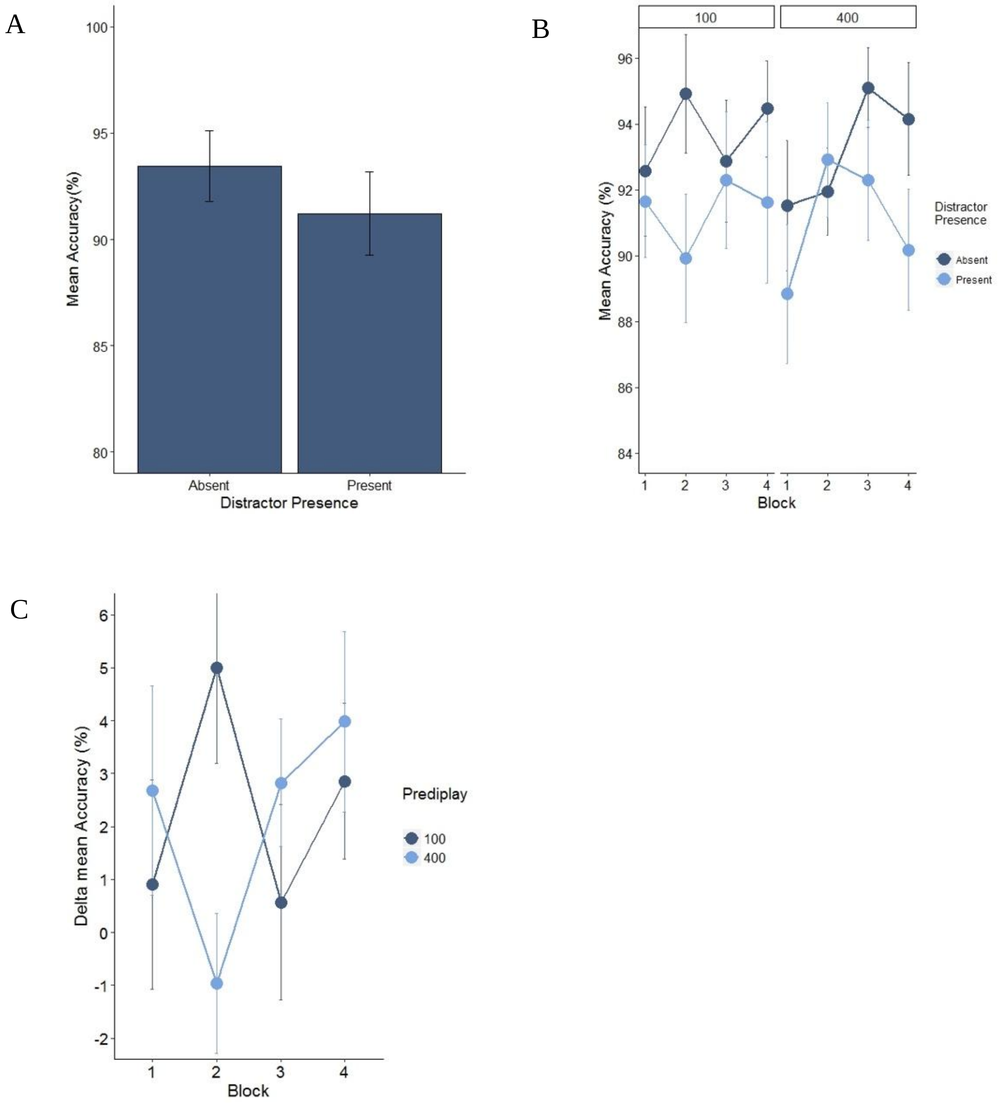


Fig.3 Image absent trials analysis. A. Main effect Distractor Presence. B. Interaction Distractor Presence as function of Block and Predisplay duration. C. Cost of Distractor as function of Block and Predisplay duration.

Another repeated measures ANOVA was carried out on the remaining 20% of trials in which, instead of images with emotional content, a colored noise was displayed. As usual, the factors considered were Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 400 ms), all within-subjects.

The ANOVA revealed a significant main effect of Distractor, $F_{(1, 19)} = 5.90$, $p = 0.02$, ηp2 = .237 reflecting again the attentional capture effect (Distractor-absent vs. Distractor-present condition: 93.44 % vs. 91.21 %) (Fig.3 panel a). The interaction of Distractor by Block by Predisplay duration was again not significant, $F_{(3, 57)} = 1.89$, $p = 0.14$ (Fig.3 panel b); in fact, the cost of distraction was constant over the experimental session and in both Predisplay conditions, as in the previous analysis (Fig.3 panel c).

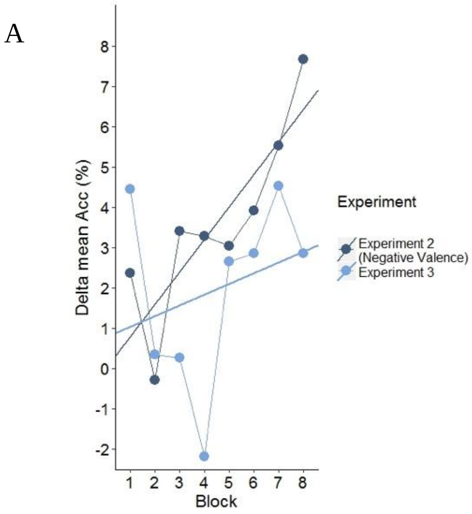


Fig.4 Image absent trials analysis. A. Linear regression analysis of cost of Distractor as function of Block and Image Valence.

Following the approach adopted above, a linear regression analysis was performed, to investigate more specifically any variations of the distractor filtering cost during the session, focusing on trials with a longer Predisplay duration and dividing the session in 8 timepoints. The linear regression however did not reach statistical significance (Fig.4 panel a).

8.3 Discussion

The principal objective of the present experiment was to establish the extent to which negative emotional stimuli exert a detrimental influence on processing resources dedicated to the working of attentional mechanisms. Several studies demonstrated that negative emotional stimuli, even if task-irrelevant, gain preferential access to cognitive control and their automatic processing can disrupt overall attentional performance and specifically target selection and distraction filtering (Hodsoll, et al., 2011; Yiend, 2010). After having established in Experiment 2 that these effects can also lead to a depletion of processing resources dedicated to selective attention, in this Experiment we wanted to investigate whether such effects can vary according to the degree to which the processing of the emotional contents of the stimuli is allowed by the experimental context. In particular, we aimed to reduce the impact of the images with negative valence, by engaging subjects on a secondary task which was to be carried out in parallel to the main visual search task and required subjects to encode and categorize the emotional images from a non-emotional perspective.

It is widely recognised that negative emotional stimuli are attention attractors and retainers (Anderson & Phelps, 2001; Keil & Ihssen, 2004; Ohman et al., 2001; Zeelenberg et al., 2006) and as a consequence they compete for processing resources, drawing them away from other concurrent stimuli and tasks (Kern et al., 2005, Helton et al., 2011). These general effects were replicated in Experiments 1 and 2, and the results of Experiment 2 further suggested that the systematic need to ignore highly interfering negative emotional stimuli caused the depletion of attentional resources in a relatively short period of time. In addition, this effect was magnified in the condition of Prediplay duration with longer timing, suggesting that the depletion of attentional resources was more marked if more time was allowed to process the semantic contents of the images, prior to the onset of the task-relevant stimuli. Based on this finding, in Experiment 3 we decided to further increase the Predisplay duration, in order to provide a larger temporal gap between the display of the emotional image and the onset of the stimuli requiring a behavioural response. We reasoned that such longer time would allow for an even deeper processing of the emotional images, leading to a more widespread engagement of different brain systems and resources. Moreover, as explained above, negative emotional stimuli have also proved to alter the subjective state, inducing conscious task-unrelated thoughts (Smallwood, et al., 2009, Smallwood, 2010) that compete for further attentional resources (McVay & Kane, 2010). By increasing the Predisplay duration we consequently expected a larger consume of attentional resources also due to the growing amount of task-unrelated thoughts that could be generated, and that might need to be suppressed.

More importantly and more relevant to our primary objective, in Experiment 3 we added another crucial manipulation. Participants were engaged in a secondary task which was to be carried out in parallel to the main visual search task. Specifically, we chose a working memory task in which subjects were asked to count and keep in mind over the experimental session all images containing animals. Hence, while leaving a longer time for the "automatic" processing of the semantic emotional content of the pictures, we also implicitly invited subjects to process them from a non-emotional perspective, focusing on scene analytical details rather than on their overall meaning. By doing this, we thought that the increased perceptual and cognitive load would leave fewer resources available and thus the interference produced by negative emotional stimuli would be reduced. In fact, many studies suggested that by increasing the cognitive or attentional load it is possible to reduce the emotionally-driven activation in regions such as the amygdala (Clarke & Johnstone, 2013; Taylor et al., 2003; Northoff et al., 2004; Van Dillen et al., 2009). The subsequent lack of available cognitive and attentional resources could limit the possibility for emotional stimuli to be processed sufficiently so to interfere with the task at hand. In line with this literature, the results of Experiment 3 indeed suggested that the impact of negative emotional stimuli on concurrent attentional tasks is not automatic, and that cognitive and perceptual load could modulate their detrimental effects on attentional mechanisms. Here in fact, contrary to what we found in the Negative image condition of Experiment 2, where the cost associated with the salient distractor in the search display increased towards the end of the session – suggesting the depletion of processing resources involved in the filtering of distracting information –the attentional capture effect observed was constant throughout the experimental session, even in the longer Predisplay duration condition.

The consistent engagement of top-down control mechanisms, elicited by the secondary task in the current Experiment might thus have facilitated the processing of task-related stimuli by protecting it from the interfering emotional effects. Such protective effect might have originated from an involvement of the prefrontal cortex, the brain area that, according to several studies, is related to the cognitive regulation of emotional responses (Davidson, 2002; Ochsner & Gross, 2005), and is known for exerting a top-down inhibitory effect on the amygdala (Pears et al., 2003; Rosenkranz et al., 2005; Izquierdo & Murray, 2005; Quirk and Beer, 2006; Carmichael & Price, 1995; McDonald et al., 1996). In fact, many studies have reported an attenuated amygdala reactivity to emotional stimuli during emotion regulation, associated with an increased activation of prefrontal brain regions (Ochsner et al., 2002; Urry et al., 2006), consistent with the notion that frontal cortex exerts a top-down inhibitory influence on the amygdala. Specifically, several fMRI studies reported an increase in activity in ventrolateral, dorsolateral and dorsomedial prefrontal cortices when the negative emotional experiences were reduced through cognitive strategies (Ochsner & Gross, 2005). This might represent a viable explanation for the reduced impact of negative images, suggesting that their emotional content could not be processed automatically.

In conclusion, with Experiment 3 we indeed observed an effective reduction of the impact that negative emotional stimuli exert on attentional mechanisms and a relative sparing of attentional resources in time.

As a next step, we decided to test whether – conversely – it was possible to increase the impact of emotional images on attentional processing resources by emphasizing the emotional response that could be generated after the presentation of each image. To this aim, we carried out another experiment in which, in order to enhance the automatic emotional responses to the negative images we introduced a Mood Induction Procedure (Bartolini E.E., 2011) which was administered to all participants before the start of the experimental session.

Chapter 9

Enhancing the detrimental effect of negative emotional stimuli

9.1 Experiment 4

With Experiment 3, we demonstrated that, by introducing a secondary task which increased the cognitive load and at the same time required subjects to analyse the emotional images from a non-emotional perspective, we were able to reduce the detrimental effects of negative images on attentional processing. This effect was most likely due to a reduction in the degree to which images with negative valence were systematically processed during the experimental session.

In this new Experiment, we aimed to obtain an opposite effect, so that by emphasizing the processing of the emotional contents of negative images, we might observe strongly disruptive effects on the deployment of attentional resources, replicating and possibly extending the findings of Experiment 2. As already discussed, previous studies suggested that the exposure to negative emotional stimuli might consume attentional resources and lead to performance costs because, by altering the subjective mood, they induce conscious thoughts that need to be suppressed (Smallwood, et al., 2007; Smallwood, et al., 2009, Smallwood, 2010; Farrin et al., 2003; Watts et al., 1988). Accordingly, fMRI studies have reported a large overlap between areas involved in the experience of sad mood and in high-level cognitive processing. Specifically, studies have revealed that sad mood exerts an influence on the activity of a common set of prefrontal and limbic brain regions (Davidson et al., 2002; Mayberg et al., 1999). For example, studies performed in normal subjects with sad mood, showed an alteration of neural activity in prefrontal cortices, specifically in dorsolateral prefrontal cortex (Aalto et al., 2002; Gemar et al., 1996; Liotti et al., 2000; Mayberg et al., 1999) and in medial regions including the anterior cingulate cortex (for reviews, see Phan et al., 2002), and an enhanced activation of the amygdala (Mayberg et al, 1999; Murphy et al., 2003; Phan et al., 2002; Phillips et al, 2003a, 2003b; Drevets, 2003; AAlto et al., 2002; Eugene et al., 2003; Lane et al., 1997; Levesque et al., 2003).

Following the evidence of distributed and overlapping substrates of sad mood and executive functions (Bower & Foras, 2001;for reviews, see Austin et al., 1999; Marvel & Paradiso, 2004; Rogers et al., 2004), and given the interactions described above between sad mood and cognitive performance, we expected that by manipulating the subjective mood of our participants, to render them even more prone to experience the negative affective/emotional value of the images shown during the experimental session, we might enhance the detrimental influence of negative emotional images on attentional processing and the depletion of the associated cognitive resources.

In Experiment 4, participants performed the same visual search task adopted in our previous Experiments, and all the experimental conditions replicated the procedure of Experiment 3, with the exception that in this case there was no secondary task to perform with respect to the emotional images, and task instructions were the same as in Experiments 1 and 2. To address our aim, however, we introduced a negative Mood Induction Procedure before the start of the experimental session, which is typically employed to induce participants to experience a specific mood, the effects of which can affect subsequent cognitive testing (for review, see Gilet, 2008).

9.2 Materials and methods

Participants

Twenty-two participants (11 males; mean age ± SD, 23.54 ± 2.93) took part in the Experiment. Two participants had to be excluded because they did not complete the experimental session. All subjects of the final sample (9 males; mean age ± SD, 23.45 ± 2.96) were right-handed and with normal or corrected-to-normal vision. Most of the participants were students at the University of Verona, Italy. None of them had previously taken part in similar or related studies, and they were all naive as to the purpose of the study. All the participants received fixed monetary compensation for their participation (15 euros) and gave written informed consent before participation. The protocol was approved by the Review Board for Studies involving Human Participants of the University of Verona, Italy.

Apparatus

In addition to the other materials, identical to those used for Experiments 1, 2 and 3, for this Experiment we developed a Mood Induction Procedure following the guidelines provided by Bartolini E.E. (Bartolini E.E., 2011), which aimed specifically at inducing sadness in participants. This consisted of a series of six movie clips ranging from 1 minutes and 27 seconds to 2 minutes and 50 seconds in length, with an average length of 2 minutes. In selecting the movie clips for inclusion in the experiment, particular relevance was given to the specific details of the scene, such as background music, length and plot details, in order to provide an intelligible plot in a short amount of time. Every clip was presented in Italian. More detailed information about each clip, including start time, end time, scene description, year of production and total run time, are provided in the Appendix 2.

Design and procedure

Design and procedure were identical to those for Experiment 3, with the exception that in this case no secondary task was to be performed with respect to the emotional images appearing prior to the search display. Task instructions were therefore the same as in Experiments 1 and 2.

Participants were seated in a dimly lit room and the experimental session started with the display of the six movie clips on the computer screen, for 15 minutes ca. After that, as in the previous experiments, they completed an initial practice block of 60 trials, followed by a single session for the experiment proper. The experimental session lasted approximately one hour and thirty minutes and consisted of 1920 trials.

Mood. To allow the formal assessment of their mood, participants were asked to complete the Profile Of Mood States (POMS) questionnaire (McNair et al., 1971), at three time-points during the experimental session: Before the mood induction procedure (T1), immediately after it (T2), and at the end of the session (T3). The questionnaire consists of 65 5-point adjective rating scales which are factored into 6 mood scores: Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigour, Fatigue and Confusion. Each of the six states is defined by adjectives descriptive of the mood which subject perceive.

Data analysis

This followed the same approach as used before. In line with what we had done in the previous experiments, data analyses were initially performed on both RTs and accuracy rates. However, since the effect of our crucial manipulation for this paradigm were better expressed by accuracy rates, for the present discussion we decided to focus on accuracy rates results. The results of the same analyses conducted on mean RTs are extensively reported in the Appendix 1 section C.

Results

Image present trials

A repeated measures ANOVA was performed on the accuracy rates of responses in the 80% of the trials, in which the images were displayed. The factors included were Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 400 ms), all within-subjects.

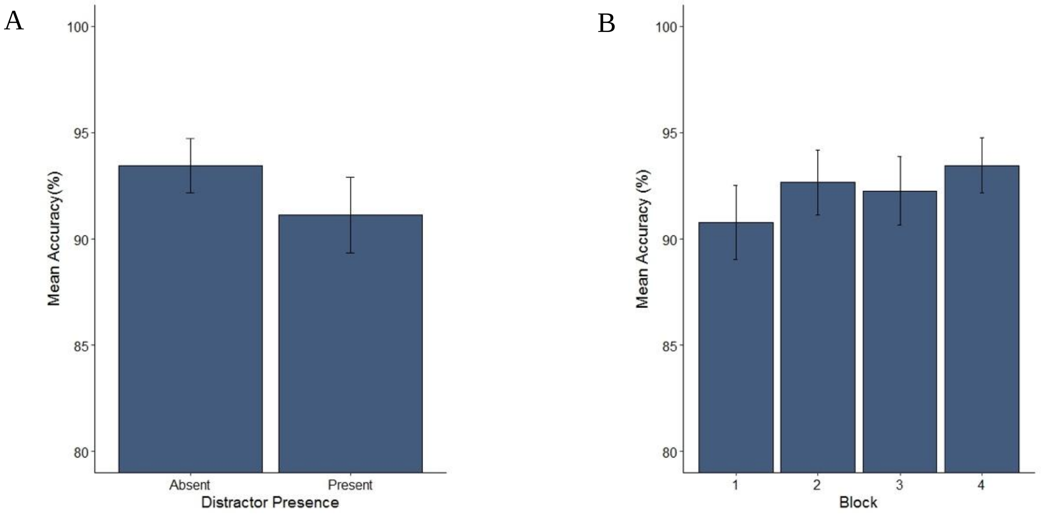


Fig.1 Image present trials analysis: Main effects. A. Main effect of Distractor Presence. B. Main effect of Block.

The ANOVA yielded a significant main effect on Distractor Presence, $F_{(1,\ 19)}$ = 10.39, p = 0.004, ηp2 = .353 indicating the attentional capture effect, as found in the previous experiments (Distractor absent vs. Distractor present condition: 93.45 % vs. 91.13 %) (Fig.1 panel a). There was also a significant main effect of Block, $F_{(3,\ 57)}$ = 3.50, p = 0.02, ηp2 = .417 suggesting that also in this experiment performance improved over time (Fig.1 panel b).

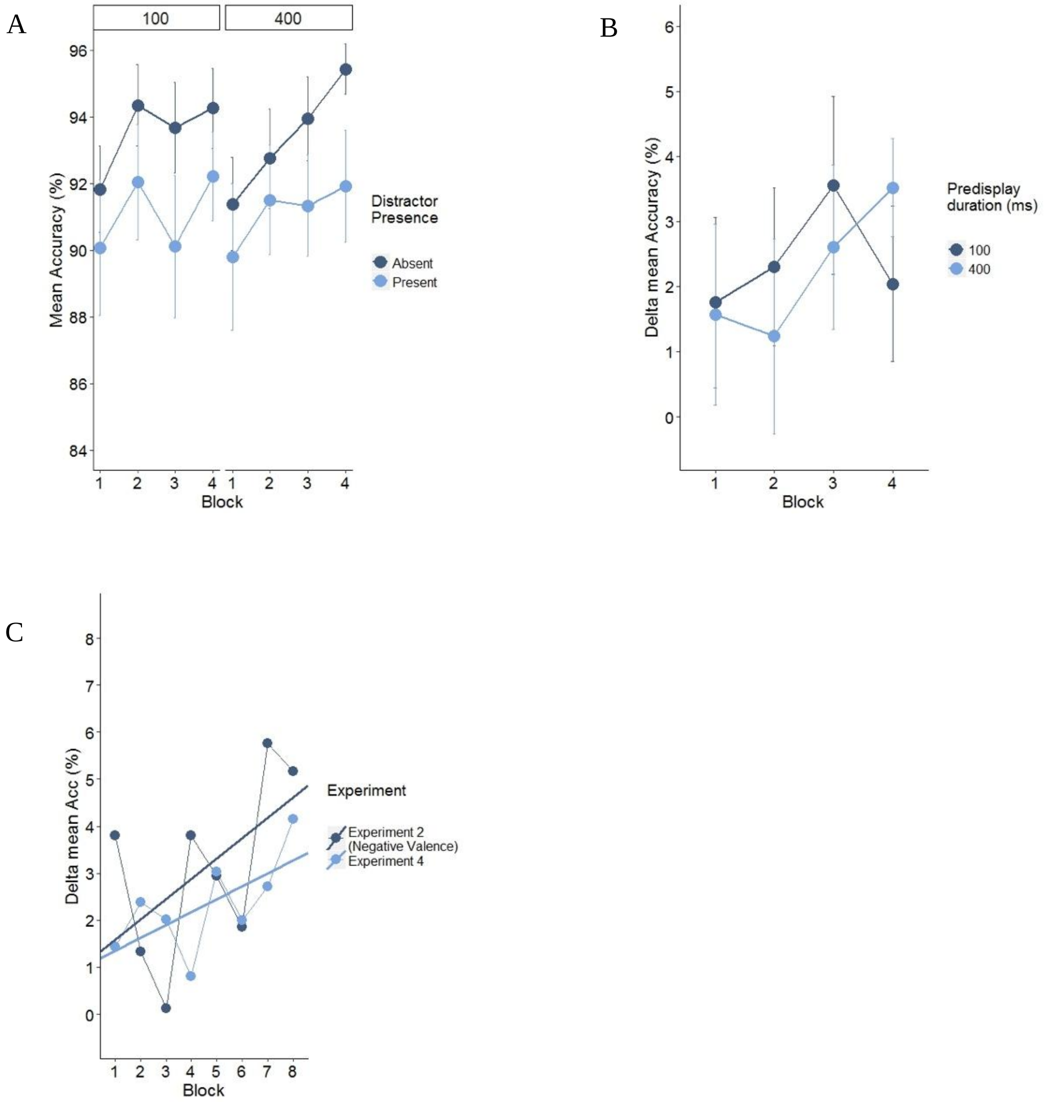


Fig.2 Image present trials analysis: Interactions between factors. A. Interaction Distractor Presence as function of Block and Predisplay duration. B. Cost of Distractor as function of

Block and Predisplay duration. C. Linear regression analysis of cost of Distractor as function of Block and Image Valence.

Interestingly, the three-way interaction Distractor by Block by Predisplay duration was not significant, $F_{(3,\ 57)} = 0.74$, $p = 0.52$ (Fig. 2 panel a). However, a close inspection of the data (Fig. 2 panel b), seemed to suggest that in the condition with a longer Predisplay duration (400 ms) the cost in distractor filtering increased over the experimental session, in line with what was previously found in the Negative value condition of Experiment 2. In fact, post-hoc comparison revealed a significant increase in cost of distractor over time only in the condition of longer Predisplay duration (Difference in Cost of distractor in trials with longer Predisplay duration, Block 1 vs. Block 4: $t_{(159)} = -3.94$, $p < .001$; Difference in Cost of distractor in trials with shorter Predisplay duration, Block 1 vs. Block 4: $t_{(159)} = -0.57$, $p = 0.56$) (Fig. 2 panel b).

As for Experiment 3, in order to conduct a more fine-grained analysis of Block-dependent variations in distractor costs, we divided each session in eight subsequent blocks to better capture any quantitative difference that might have emerged over time, and performed a linear regression analysis, on cost as a function of Block (Fig. 2 panel c). We considered the condition with longer Predisplay duration (400 ms) since the main results of Experiment 2 were obtained in this condition. The linear regression analysis did not reach statistical significance, $F_{(1,37)} = 0.22$, $p = 0.63$. As we expected, however, the cost seemed to vary linearly, as a function of Block, expressing the same trend that had emerged in Experiment 2. As can be appreciated in Figure 2 panel c, in both the Negative condition of Experiment 2 and in the present one, the trend seemed to reflect an increasing cost due to distractor filtering over time. By comparing directly the coefficients of the linear regressions conducted on the two experiments we were able to establish that they were not significantly different ($t_{(19)} = 0.48$, $p = 0.63$; Bayes Factor = 0.257).

Image absent trials

As usual, another ANOVA was performed on the remaining 20% of trials in which, instead of images with emotional content, coloured noise was displayed. We considered the same within-subjects factors of the previous analysis, which were Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 400 ms).

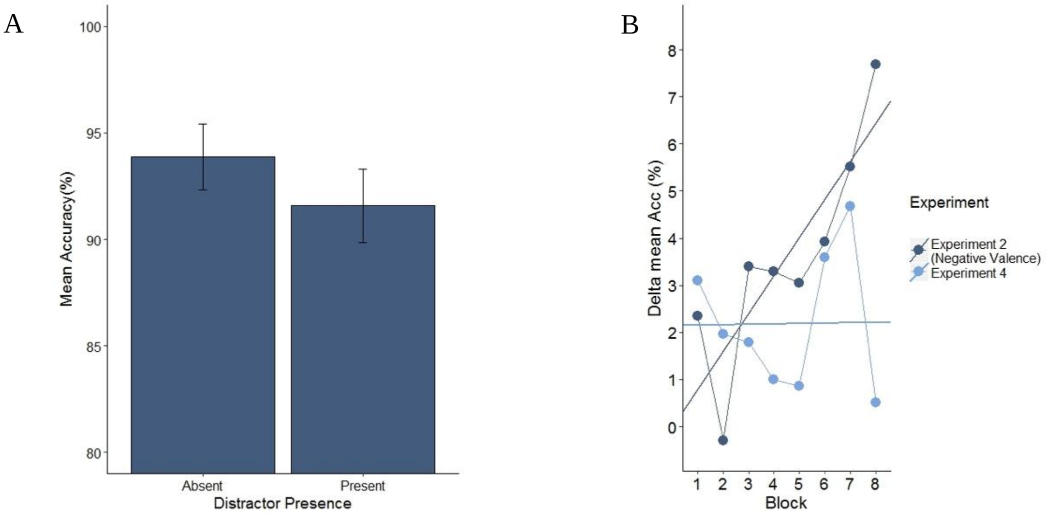


Fig.3 Image absent trials analysis. A. Main effect of Distractor Presence. B. Linear regression analysis of cost of Distractor as function of Block and Image Valence.

The ANOVA revealed a significant main effect of Distractor, $F_{(1, 19)} = 9.66$, $p = 0.005$, ηp2 = .337, reflecting again the attentional capture effect (Distractor absent vs. Distractor present condition: 93.87 % vs. 91.57 %) (Fig. 3 panel a). In line with the approach adopted with respect to the trials in which an image was present, we performed separate linear regression analyses on costs by Block in the present Experiment and in the corresponding conditions of Experiment 2, focusing on trials with a longer Predisplay duration (which was 200 ms in Exp.2 and 400 ms in the present one). The result however did not reach statistical significance, $F_{(1,33)} = 1.75$, $p = 0.19$ (Fig. 3 panel b).

POMS results

Paired comparisons were conducted to establish the degree to which the Mood Induction Procedure had been able to affect mood in the participants. The results of such t-tests showed significant differences between T1 and T2 (Mean POMS T1 vs. T2: 95.5 vs. 103; $t_{(19)} = -2.66$, $p = 0.01$), suggesting that participants were successfully induced into a sad mood by the viewing of the movie clips. Specifically, a significant increase was observed in the Depression-Dejection and Tension-Anxiety subscales (Mean Depression-Dejection T1 vs. T2: 2.7 vs 4.6; $t_{(19)} = -2.54$, $p = 0.01$; Mean Tension-Anxiety T1 vs. T2: 4.95 vs 7; $t_{(19)} = -2.39$, $p = 0.02$) while, on the other hand, a significant decrease in the score of the Vigour subscale was found (Mean Vigour T1 vs. T2: 8.95 vs 6.4; $t_{(19)} = -3.12$, $p = 0.005$), reflecting lower level of activity as participants became more sad. Importantly, no significant changes in the Fatigue subscale were registered (Mean Fatigue T1 vs. T2: 5.55 vs 4.75; $t_{(19)} = 1.41$, $p = 0.17$), nor in Anger-Hostility and Confusion subscales (Mean Anger-Hostility T1 vs. T2: 2.2 vs 2.9; $t_{(19)} = -1.02$, $p = 0.31$; Mean Confusion T1 vs. T2: 4.45 vs 3.9; $t_{(19)} = 0.89$, $p = 0.38$).

Interestingly, the comparison between the overall POMS scores at T2, immediately after Mood induction, and at T3, at the end of the entire experimental session, was also significant (Mean POMS T2 vs. T3: 103 vs. 111.75; $t_{(19)} = -3.04$, $p = 0.006$), suggesting that participation in the experiment proper further affected mood in participants. Nevertheless, no differences were found in the Depression-Dejection and Tension-Anxiety subscales (Mean Depression-Dejection T2 vs. T3: 4.6 vs 4.3; $t_{(19)} = 0.33$, $p = 0.74$; Mean Tension-Anxiety T2 vs. T3: 7 vs 5.65; $t_{(19)} = 1.65$, $p = 0.11$), while a significant decrease in the Vigour subscale emerged (Mean Vigour T2 vs. T3: 6.4 vs 5.2; $t_{(19)} = 2.39$, $p = 0.02$). Importantly, and in line with this result, a significant increase in the Fatigue subscale was found (Mean Fatigue T2 vs. T3: 4.75 vs 10.25; $t_{(19)} = -4.64$, $p < .001$), as well as in the Confusion subscale (Mean Confusion T2 vs. T3: 3.9 vs 10.25; $t_{(19)} = -4.64$, $p < .001$). Finally, no significant difference was found in the Anger-Hostility subscale (Mean Anger-Hostility T2 vs. T3: 2.9 vs 3.85; $t_{(19)} = -1.07$, $p = 0.29$). These data suggested that while the relevant measures associated with sadness were unchanged at the end of the experiment, the need for participants to implement cognitive strategies throughout the session in order to control and suppress their emotional responses led to a diminished level of energy and vigor which clearly reflected mental fatigue and confusion.

9.3 Discussion

It is widely demonstrated that emotional stimuli, even if task-irrelevant (Fox et al., 2001), access attentional resources, becoming prioritized over other competing stimuli, probably because of their intrinsic significance (Vuilleumier, 2005). Specifically, several studies have demonstrated that negative emotional stimuli in particular elicit more prominent and rapid responses compared to neutral and positive ones (Hansen et al., 1988; Pratto et al., 1991, Carretiè et al., 2000). This "negativity bias" has been largely studied, and seems to involve different response systems, such as those related to cognitive, emotional and social behaviour (Cacioppo & Gardner, 1999; Mogg et al, 1998; Mogg et al., 2000; Peeters & Czapinsky, 1990; Taylor, 1991). Along these lines, it has been also proposed that, since they are so powerful in capturing and retaining attention, once detected negative stimuli require more attentional resources in order to be ignored and allow the processing of concurrent task-relevant information (Kern et al., 2005; Helton et al., 2011). In addition, the possibly threatening nature of these stimuli may also alter subjective mood and encourage more elaborate off-task processing (Smallwood et al., 2009; Smallwood, 2010). In line with this literature, in Experiment 2 indeed we demonstrated that stimuli with negative emotional content, compared to neutral and positive ones, impaired performance in a typical selective attention task, thus reflecting a greater interference on attentional processing mechanisms specifically involved in target selection and distraction filtering. Based on those results, we subsequently aimed to manipulate the degree to which the systematic processing of the images with negative valence was allowed during the course of the experiment. Conversely to Experiment 3, in which we wanted to reduce the impact of the images with negative valence, in Experiment 4 we aimed to emphasize the emotional response that could be generated after the presentation of each image by introducing a Mood Induction Procedure before the start of the experimental session, which is thought to enhance the processing of emotional information. Smallwood and colleagues (2009) showed higher level of task-unrelated thoughts after a mood induction procedure (Smallwood et al., 2009). When the mood induced has a negative effect, this seems to induce self-focused attention (Salovey, 1992; Sedikides, 1992; Wood et al., 1990; Wood et al., 1990) and attention to somatic activity (Stegen et al., 2001). Helton and colleagues demonstrated that intrusive thoughts per se are correlated with decreased target detection performance (Helton & Warm, 2008). Therefore, we hypothesized that, when in a sad mood, participants could experience a larger amount of task-unrelated thoughts that, in order to be suppressed, would also compete with the primary task for access to attentional processing resources. The relationship between sad mood and negative emotional stimuli might therefore be bidirectional: the display of negative stimuli might induce sadness, and a sad mood might enhance the degree of processing of negative emotional stimuli (McVay & Kane, 2010; Smallwood, 2010). Based on this literature, we expected that, altogether, the larger consume of processing resources, also required in order to suppress task-unrelated thoughts, would interfere with the resources devoted to the suppression of emotional responses and distraction filtering which throughout the experimental session were also heavily engaged by the main task.

Furthermore, it is known that, from an anatomical perspective, mood influences many of the brain region subserving memory, attention, perception and executive functions. In fact, these regions might become more or less active when experiencing a sad mood compared to a neutral one. Functional neuroimaging studies suggested that the anatomical bases of sad mood and of higher-order cognitive processing may be largely overlapping. Specifically, studies demonstrated that the activity of a common set of prefrontal and limbic brain regions is influenced by sad mood, among which dorsolateral (Aalto et al., 2002; Gemar et al., 1996; Liotti et al., 2000; Mayberg et al., 1999) and medial regions (for reviews, see Phan et al., 2002) of prefrontal cortex and the amygdala (Davidson et al., 2002; Mayberg, 1999; Murphy et al., 2003; Phan et al., 2002;

Philips M.L. et al., 2003a, 2003b; Aalto et al., 2002; Eugene et al., 2003; Lane et al., 1997; Levesque et al., 2003). Therefore, on the basis of this overlap in both cognitive and neural mechanisms involved in dealing with negative emotions and attentional filtering, we expected that by inducing sadness, and consequently increasing the affective engagement during exposure to negative emotional images, we would have observed increased costs in task performance and an accentuated depletion of attentional resources within the session.

Differently from what we expected, in Experiment 4 we were not able to observe a significant depletion of attentional resources within the experimental session. Indeed, the Mood Induction Procedure, based on movie clips that we had collected, proved to be effective in inducing a sad mood. In fact, significantly higher levels of depression and tension were reported by subjects following the procedure, while, on the other hand, the levels of enthusiasm and general vivacity were lower. However, although participants were in a sad mood, the main results suggested that this manipulation was less powerful than we had anticipated, leading to non-significant effects. In fact, we could not demonstrate that, after the viewing of the movie clips, the emotional response engendered by the presentation of images with negative emotional content was emphasized.

A close inspection of the data however seemed to indicate a trend in line with what emerged in Experiment 2, namely that as the session proceeded, the costs associated with distractor filtering increased, and especially so in trials with a longer Predisplay interval, which allowed a deeper processing of the negative valence images prior to stimulus display. While the results of Experiment 4 (i.e., in Image present trials, the interaction between Distractor presence, Block and Predisplay duration) failed to reach significance, a direct comparison between the linear regression coefficients of the function, describing how Distractor filtering cost was affected by Block in Experiment 2 and 4, suggested that the two did not differ significantly. Interestingly, in both cases the trend was quite the opposite to what had emerged in Experiment 3, which aimed on the contrary to reduce the impact of emotional images.

There are a number of possible explanations for why the depletion of attentional resources in Experiment 4 did not reach statistical significance. One for example may be found in a lack of statistical power, due to a relatively small sample size. Another possible explanation might be due to the individual features of the participants involved in this and all the Experiments in this study, which might have had a role in two different domains. In fact, they were all students at the Medical School, and presumably with particularly high cognitive skills and greater availability of cognitive resources. For this reason, it is possible that, with respect to the general population, these highly-performing subjects might be more resilient with respect to depletion of cognitive and attentional resources. Therefore, it is possible that if the same study were conducted on specific populations which are characterized by different levels of cognitive abilities or limited cognitive resources, such as anxious or depressed subjects, subjects with neuropsychological disorders or, simply, healthy older adults, the results obtained might have been quite different, and it will be interesting to investigate this possibility in future developments of this study.

Moreover, in this Experiment, as well as in all those described as part of the study, interpersonal differences might have played a crucial role in modulating the overall sensitivity to the emotional stimuli, and, as a consequence, also their impact on attentional processing. In this Experiment in particular, our goal might have been additionally hindered by individual differences in the sensitivity to the Mood Induction Procedure. In order to explore this possibility, we selected four participants from our sample, the two subjects that showed the highest and the lowest score respectively at POMS questionnaire, which indexes the sensitivity to the Mood Induction Procedure, or how strongly the viewing of negatively valued emotional movie clips induced a sad mood. Interestingly, we could observe substantial differences in their performance during the main task, suggesting that they were differently affected by the negative mood and the negative content of the images shown during the experiment.

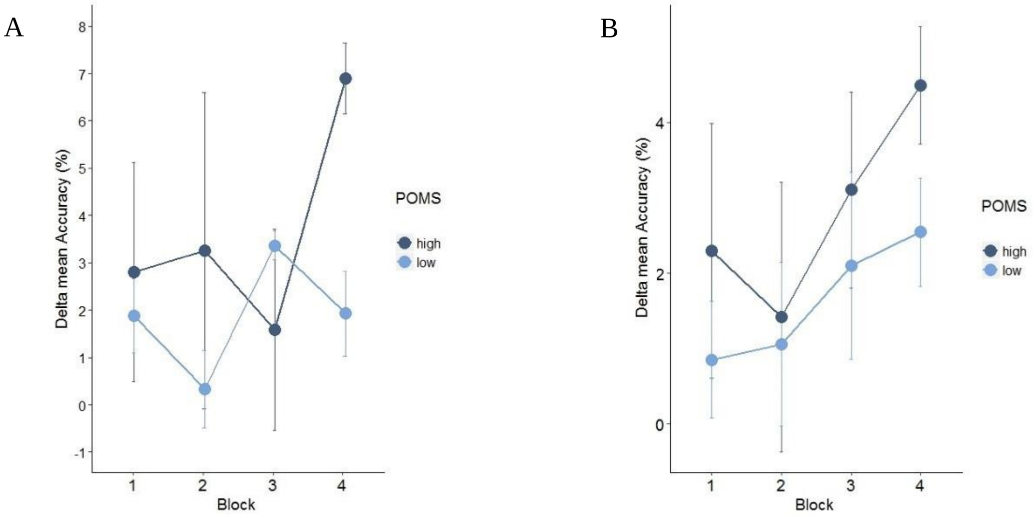


Fig.4. A. Interaction between POMS score and cost of distractor in individuals with extreme values. B. Interaction between median split POMS score and cost of distractor in all sample.

As shown in figure 4 panel a, participants who scored higher at POMS, thus reflecting the highest level of induced sad mood, showed a systematic increase in the cost of distractor filtering over the experimental session, perfectly in line with the expected results. Conversely, participants who scored lower at the POMS, and therefore were not affected by the negative mood induction and perhaps were also less sensitive to the negative emotional effects engendered by the images, showed no variations in the cost of distractor filtering over time. In order to explore more systematically the impact of such individual differences we carried out a new ANOVA, with the same within-subjects factors considered in the main data analyses, in which the sample was divided in two subsets, according to a median split of POMS scores. Although the data were in line with those observed in individuals with extreme values (Fig.4 panel b) none of the effects reached statistical significance, perhaps because of the limited size of our sample (overall 20 subjects, 10 per POMS group).

This preliminary evidence however suggests that individual differences in the permeability of one’s mood with respect to external stimuli with an emotional content might be crucial in supporting the results at the core of this investigation. While a substantial depletion of attentional resources over time is found in subjects who are more sensitive to negatively valued emotional stimuli, and presumably make a stronger effort to counteract the impact of these images during the course of the experimental session, subjects who are less permeable to these emotional stimuli, and therefore need less resources to ignore them, show no signs of depletion.

Chapter 10

Concluding remarks

The scope of this work has been that of directly exploring whether it is possible to deplete – in a relatively short period of time – a specific pool of cognitive resources dedicated to visual selective attention. To this aim, we performed a series of visual selective attention experiments based on an Attentional Capture task (Theeuwes, 1994), in which subjects had to detect and discriminate a target that could be accompanied by a salient irrelevant distractor. In order to give rise to a heavy and persistent condition of distraction we introduced a crucial manipulation, which posed great stress by overloading attentional mechanisms. Prior to the display of task relevant information we introduced images with a high emotional content since they are known to be powerful in attracting and holding attention even when they are irrelevant, such as in this case (Hodsoll et al., 2011; Yiend, 2010). Subjects were instructed to focus their attention on the main task, while ignoring both the emotional images and the response that they might have engendered, as well as the salient distractor when it was present in the trial.

In Experiment 1, we firstly demonstrated the efficacy of our paradigm in giving rise to attentional capture (Theeuwes, 2004) within a very cognitively demanding task, which aimed at posing a great stress on attentional resources. By dividing the entire timeline of the experimental session in consecutive blocks, we could monitor any changes in performance and in attentional capture over time. However, differently from what we might have expected, we could not observe any sign of depletion. Despite all the manipulations applied in order to overload the attentional system, performance seemed to improve over time, suggesting, in line with previous studies, that attentional processing – including distractor filtering – can improve over time with practice (Kelley & Yantis, 2009; Turatto & Pascucci, 2016). Regarding the impact of emotional images, we could demonstrate that they indeed exerted a detrimental influence on attentional processing. In particular, greater cost in distractor filtering performance was found in association with images with negative emotional content. However, also the overall interference produced by the images became weaker toward the end of the session. It is plausible to think that subjects became better capable in managing the emotional responses engendered by the images over time. One possible reason could be that in this Experiment each image was repeated four times during the session and, therefore, subjects might have become familiar with their content, and this could have contributed to decrease their arousing effect over time. Another complexity arose from the fact that all images (negative and positive) were intermixed during the session. Therefore, if any detrimental effects were triggered by the negative images, the subsequent processing of an image with positive valence might have helped “restore” any disruption, and/or vice versa (Helton & Russell, 2011), since several studies demonstrated the beneficial effects of natural scenarios on attention and memory, and, more generally, on cognition (Berman, et al., 2008; Berto, 2005; Cimprich & Ronis, 2003; Faber, Taylor, Kuo, & Sullivan, 2002; Hartig et al., 2003; Tennessen & Cimprich, 1995).

To overcome these issues, we designed another experiment, Experiment 2, in order to explore more directly the impact exerted by the images on attentional mechanisms. Two main variations were introduced with respect to the method of Experiment 1. Firstly, the emotional valence of the images displayed on each trial was manipulated as a between-subjects factor and, thus, each group of subjects was exposed to images of only one valence (positive, negative or neutral). Second, we increased the set size of the emotional images, so that each one of them was displayed only once. Again, results of Experiment 2 confirmed an attentional capture effect since the capture by the salient distractor disrupted the ongoing task. More importantly and more interestingly, we demonstrated that the attentional mechanisms involved in distraction filtering were affected differently by the different emotional content of the images. The presence of the image was always detrimental for task performance. Additionally, negative and positive images had an opposite effect on the ongoing attentional processing, with only negative images leading to a significant increase of attentional capture with time on task. This result was not only in line with previous studies that claimed that emotional stimuli, even if task-irrelevant, capture attention, thus disrupting the ongoing task (Hodsoll, et al., 2011; Yiend, 2010), but also with the evidence of a stronger bias toward negative stimuli. According to this perspective, negative stimuli elicit more rapid and prominent responses than do positive and neutral ones, because of their higher relevance for evolutionary purposes (Armony & Dolan, 2002; Erthal, et al., 2005; Pessoa, et al., 2005; Anderson, et al., 2003;

Mogg & Bradley, 1998; Mogg, 2000; Baumeister, et al., 2001; Cacioppo & Gardner, 1999; Taylor, 1991). In addition, it has been shown that negative emotional stimuli compete heavily for attentional resources as they appear to capture and retain attention (Kern, 2005, Helton et al., 2011). In line with this literature, we indeed could assist to a depletion of attentional resources in a very short period of time, i.e. one-hour session, only in the group with negative valence images. In contrast, an improvement in performance was registered in the groups to witch neutral and positive images were shown at the start of each trial. Moreover, based on previous studies which claimed the beneficial influence of natural scenarios on cognition, we indeed could observe a greater reduction of attentional capture cost in the group with positive images since many images of our positive sample represented natural scenes (Berman, et al., 2008; Berto, 2005; Cimprich & Ronis, 2003; Faber, Taylor, Kuo, & Sullivan, 2002; Hartig et al., 2003; Tennessen & Cimprich, 1995). Interestingly, by analysing performance to the small proportion of trials that were not preceded by emotional images in each group (20% of the total trials) we could observe differences across groups that were in line with those found in image-present trials. We hypothesise that these effects might be due to the prolonged exposure to emotional stimuli during the whole experimental session, which gave rise to an emotional context, which extended and amplified the impact of the emotional images shown. Importantly, all of these effects emerged more markedly in trials with a longer Predisplay interval, which intervened between the offset of the image and the onset of the task relevant stimuli, and therefore allowed for a deeper processing of the images prior to task performance.

The results of Experiment 2 suggested that emotional negative stimuli indeed exerted a detrimental effect on attentional resources, and following this evidence we asked whether such effects could vary according to the degree to which the processing of the emotional contents of stimuli is allowed by the experimental context. We set out two further experiments with the aim on the one hand to replicate the general context of the Negative image condition of Experiment 2, and, on the other hand, to either reduce (Experiment 3) or increase (Experiment 4) the degree to which the systematic processing of the negative images was allowed during the course of experiment.

In Experiment 2 we found that the impact of negative emotional images on the depletion of attentional resources was maximum when more time (i.e. 200 ms) was allowed for the processing of emotional information. Therefore, in the subsequent experiments we decided to display only negative emotional images and to increase the “long” Predisplay so that it could vary between 100 or 400 ms. This created a larger temporal gap which allowed, in trials with a long Predisplay duration, a greater opportunity for the emotional contents to exert their influence on attentional mechanisms and determine a greater consumption of attentional resources.

Starting from this premise, Experiment 3 was designed in order to reduce the detrimental effects that negative emotional stimuli exerted on attentional mechanisms. To this aim, a secondary working memory task was introduced and was to be performed in parallel to the main task. Indeed, contrary to what found in the Negative image condition of Experiment 2, the attentional capture effect was constant throughout the experimental session, even in the longer Predisplay duration. This finding suggested that the secondary task might have facilitated the processing of task-related stimuli while avoiding the interfering emotional effects by the consistent engagement of top-down mechanisms. A viable explanation for such protective effect might be due to the involvement of medial prefrontal cortex, which is known to play a role in cognitive regulation of emotional responses (Davidson, 2000; Ochsner & Gross, 2005) and for exerting a top-down inhibitory effect on the amygdala (Pears et al., 2003; Rosenkranz et al., 2005; Izquierdo & Murray, 2005; Quirk and Beer, 2006; Carmichael & Price, 1995; McDonald et al., 1996). In fact, many studies reported an attenuated amygdala reactivity to emotional stimuli during emotion regulation, associated with an increased activation of prefrontal brain regions (Ochsner & Gross, 2005). Thus, with Experiment 3 we indeed observed an effective reduction of the impact that negative emotional stimuli exert on attentional mechanisms. It is plausible to think that in these circumstances their emotional content could not be processed in an automatic way.

Conversely, Experiment 4 was set out in order to emphasize the processing of the emotional contents of negative images in order to observe strongly disruptive effects on the deployment of attentional processing resources. As already discussed, previous studies suggested that the exposure to negative emotional stimuli might consume attentional resources and lead to performance costs since, by altering subjective mood, they encourage concurrent task-unrelated thoughts that compete with the primary task for access to attentional processing resources in order to be suppressed (Smallwood et al., 2007; Smallwood et al., 2009; Smallwood, 2010; Farrin et al., 2003; Watts et al., 1988). Accordingly, fMRI studies have reported a large overlap between areas involved in the experience of sad mood and executive functions (Davidson et al., 2002; Mayberg et al., 1999). Based on the this evidence of overlapping substrates, and given the interaction between sad mood and cognitive performance, we expected that by inducing a sad mood in our participants, we might enhance the detrimental influence of negative emotional images on attentional processing and the depletion of the associated cognitive resources. To this aim, we introduced a Mood Induction Procedure before the start of the experimental session. Although we observed a significant induction of a sad mood in our participants to Experiment 4, we could not observe a significant depletion of attentional resources within the experimental session. Although the attentional capture effect did not become lower with increasing time on task, neither did it become significantly higher at the end of the session. Overall, the effects of the mood manipulation seemed less powerful than we had anticipated, leading to non-statistically significant effects. However, a close inspection of the data seemed to indicate a trend in line to what emerged in Experiment 2, and in particular, the cost associated with distractor filtering did increase numerically throughout the experimental session, and especially so in trials in which a negative image was present and with a longer Predisplay duration. A direct comparison between the functions describing how attentional capture effects changed with time on task suggested that the trends of Experiment 2 and 4 were similar to each other and both quite the opposite of Experiment 3, which indeed aimed to reduce the impact of emotional images.

We must acknowledge that this evidence is based on a qualitative assessment of the results. Nonetheless, there are a number of possible explanations for why these findings were not supported also by statistical significance. Firstly, the relatively small sample size considered in our experiments could have reduced the statistical power of the study. Another possible reason might be ascribed to the individual features of our participants, since they were all students of the Medical School and presumably high-performing subjects with a greater-than-average availability of cognitive resources. Therefore, it would be interesting to conduct the same study on different populations, with different levels of cognitive abilities or limited cognitive resources, such as depressed or anxious subjects, subjects with neuropsychological disorders, or, simply, healthy older adults. In these samples we would expect to observe clearer signs of depletion of attentional resources, which might also become evident earlier within the session.

In conclusion, the findings collected with this work offer new evidence relative to the depletion of cognitive resources specifically associated with selective attention. Differently from mental fatigue, which reflects the depletion of general cognitive resources after a long time on task (i.e. 3-4 hours), we demonstrated that these domain-specific resources can be depleted in a relatively short period of time (i.e. one-hour session).

Our findings provide new evidence in line with previous results showing that emotional activation can either enhance or impair cognitive performance, as a function of the emotional valence of the stimuli involved, with negative emotions leading to detrimental effects (Experiments 1, 2 and 4), and positive emotions leading to opposite, restorative effects on cognitive resources (Experiments 1, and 2).

Last, but not least, our results also provide fundamental evidence on the fact that under conditions of high load on attentional processing, the active engagement of top-down behavioural control may limit, or even abolish, the detrimental effects of negative emotional stimuli (Experiment 3).

Appendix 1

A. Results of the analysis on Reaction Times of Experiment 2

Image present trials

RTs of correct responses on the 80% of trials in which the images were displayed were entered into a mixed effect ANOVA including Valence (neutral, positive and negative) as a between subject factor, and Distractor Presence (present or absent), Block (1-4), and Predisplay duration (100 or 200 ms) as within-subject factors.

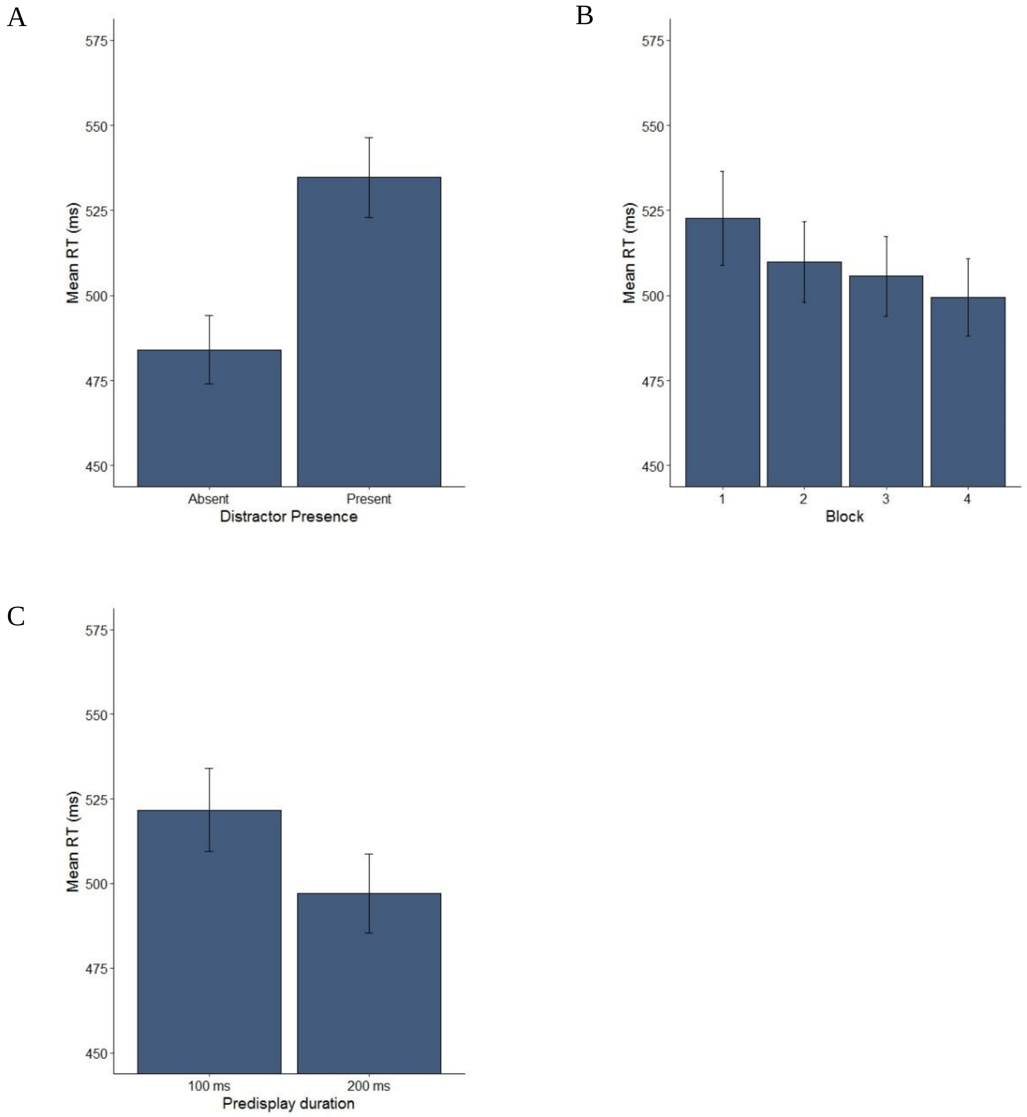
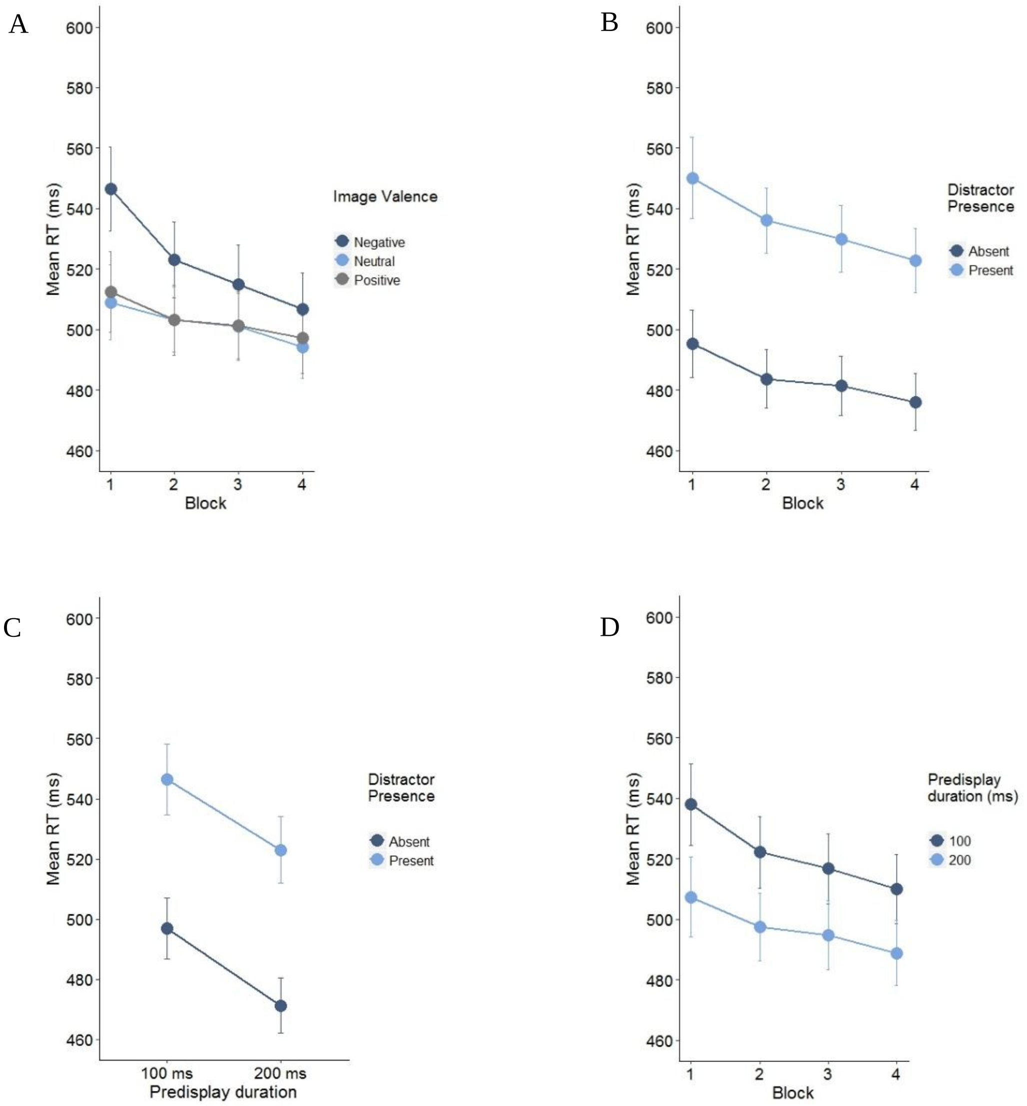


Fig.1 Image present trials analysis: Main effects. A. Main effect of Distractor Presence. B. Main effect of Block. C. Main effect of Predisplay duration.

The ANOVA revealed a main effect of Distractor Presence, $F_{(1, 57)}$= 555.96, p < .001, ηp2 = .907, with faster RTs in the Distractor-absent condition compared to the Distractor-present condition (484.08 ms vs. 534.73 ms), thus reflecting attentional capture (Fig.1 panel a). The main effect of Block was also significant, $F_{(3, 171)}$= 21.26, p < .001, ηp2 = .364, revealing faster RTs toward the end of the session (Fig.1 panel b). The main effect of Predisplay duration was also significant, $F_{(1, 57)}$= 315.38, p < .001, ηp2 = .846, with RTs being overall faster in the longer Predisplay interval (521.71 ms vs. 497.09 ms) (Fig.1 panel c).



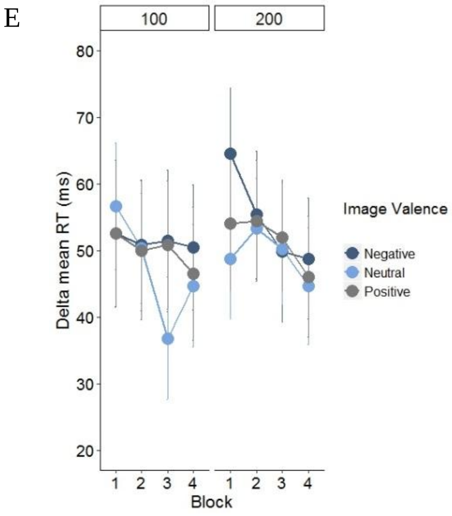


Fig.2 Image present trials analysis: Interactions between factors. A. Image Valence as function of Block. B. Distractor Presence as function of Block. C. Distractor Presence as a function of Predisplay duration. D. Predisplay duration as function of Block. E. Cost of Distractor as a function of Image Valence, Block and Predisplay duration.

Interestingly, the interaction between Valence and Block was significant, $F_{(6, 171)}$= 3.05, p = 0.007, ηp2 = .066, suggesting that although RTs improved across consecutive blocks in all of the three groups (mean RTs by Block: Neutral Valence, Block 1 = 508.97 ms, Block 2 = 503.28 ms, Block 3 = 501.10 ms, Block 4 = 494.25 ms; Positive Valence, Block 1 = 512.52 ms, Block 2 = 503.07 ms, Block 3 = 501.19 ms, Block 4 = 497.13 ms; Negative Valence, Block 1 = 546.52 ms, Block 2 = 523.11 ms, Block 3 = 514.90 ms, Block 4 = 506.82 ms), this effect was more marked for the group with Negative Valence images, which showed a greater decrease in RTs across blocks (Neutral Valence, Block 1 vs. Block 2: $t_{(79)}$= 1.80, p = 0.07, Block 2 vs. Block 3: $t_{(79)}$= 0.9, p = 0.36, Block 3 vs. Block 4: $t_{(79)}$= 2.95, p = 0.004; Positive Valence, Block 1 vs. Block 2: $t_{(79)}$= 2.70, p = 0.008, Block 2 vs. Block 3: $t_{(79)}$= 0.98, p = 0.32, Block 3 vs. Block 4: $t_{(79)}$= 1.82, p = 0.07; Negative Valence, Block 1 vs. Block 2: $t_{(79)}$= 9.34, p < .001, Block 2 vs. Block 3: $t_{(79)}$= 4.25, p < .001, Block 3 vs. Block 4 : $t_{(79)}$= 4.86, p < .001) (Fig.2 panel a). The interaction between Block and Distractor Presence was also significant, $F_{(3, 171)}$= 6.18, p < .001, ηp2 = .224 (Fig.2 panel b). RTs were significantly slower in the Distractor-present condition compared to the

Distractor-absent condition in all of the four Blocks (Distractor-present vs. Distractor-absent, Block 1: $t_{(119)}$= -24.50, p < .001; Block 2: $t_{(119)}$= -26.78, p < .001; Block 3: $t_{(119)}$= -24.93, p < .001; Block 4: $t_{(119)}$= -25.45, p < .001). However, the cost associated with Distractor presence was significantly different between Blocks. In fact, a significant decrease in distractor cost was observed only between Blocks 2 and 3 (Difference in cost of Distractor, Block 1 vs. Block 2: 54.83 ms vs. 52.38 ms, $t_{(119)}$= -1.15, p = 0.24; Block 2 vs. Block 3: 52.38 ms vs. 48.53 ms, $t_{(119)}$= -2.04, p = 0.04; Block 3 vs. Block 4: 48.53 ms vs. 46.87 ms, $t_{(119)}$= 0.82, p = 0.41). The interaction between Distractor and Predisplay duration was marginally significant, $F_{(1,\ 57)}$= 3, p = 0.08, ηp2 = .050 (Fig.2 panel c). Although in both the Distractor-present and absent trials RTs were faster in the longer predisplay interval (100 ms vs. 200 ms Predisplay duration, Distractor-present trials: $t_{(239)}$= 19.64, p < .001; Distractor-absent trials: $t_{(239)}$= 23.23, p < .001), the cost due to the presence of distractor was slightly higher in trial with a longer Prediplay duration (Distractor-present vs. Distractor-absent difference, with 100 ms Predisplay duration, 49.48 ms, vs. 200 ms Predisplay duration, 51.82 ms; $t_{(239)}$= -1.68, p = 0.09). Also the interaction between Predisplay and Block was significant, $F_{(3,\ 171)}$= 11.33, p < .001, ηp2 = .326, suggesting that although the difference between the two Predisplay conditions was significant in all blocks, (Trial with 100 ms vs. 200 ms Predisplay duration, Block 1: $t_{(119)}$= 17.93, p < .001, Block 2: $t_{(119)}$= 15.63, p < .001, Block 3: $t_{(119)}$= 13.34, p < .001, Block 4: $t_{(119)}$= 14.51, p < .001), it was significantly greater in Block 1 with respect to all the others (difference between predisplay 100 and 200, Block 1 vs. Block 2: $t_{(119)}$= 3.00, p = 0.003, Block 2 vs. Block 3: $t_{(119)}$= 1.48, p = 0.14, Block 3 vs. Block 4: $t_{(119)}$= 0.47, p = 0.63) (Fig.2 panel d). Interestingly, the 4-way interaction between Valence, Distractor, Block and Predisplay was also significant, $F_{(6,\ 171)}$= 2.35, p = 0.03, ηp2 = .097 (Fig.2 panel e). To better understand this interaction, we performed two separate ANOVAs, analyzing separately trials with different Predisplay durations. In these analyses we focused on the interaction between Valence, Distractor and Block, which would provide crucial results with respect to our aims. This interaction however did not reach statistical significance in either Predisplay duration (Predisplay 100 ms, $F_{(6,\ 171)}$= 1.69, p = 0.12; Predisplay 200 ms ms, $F_{(6,\ 171)}$= 1.22, p = 0.29).

Image absent trials

Another repeated measures ANOVA was carried out on the remaining 20% of trials, in which, instead of the images with emotional content, a colored noise display was presented. We considered Valence (neutral, positive, and negative) as a between-subjects factor, Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 200 ms) as within-subjects factors.

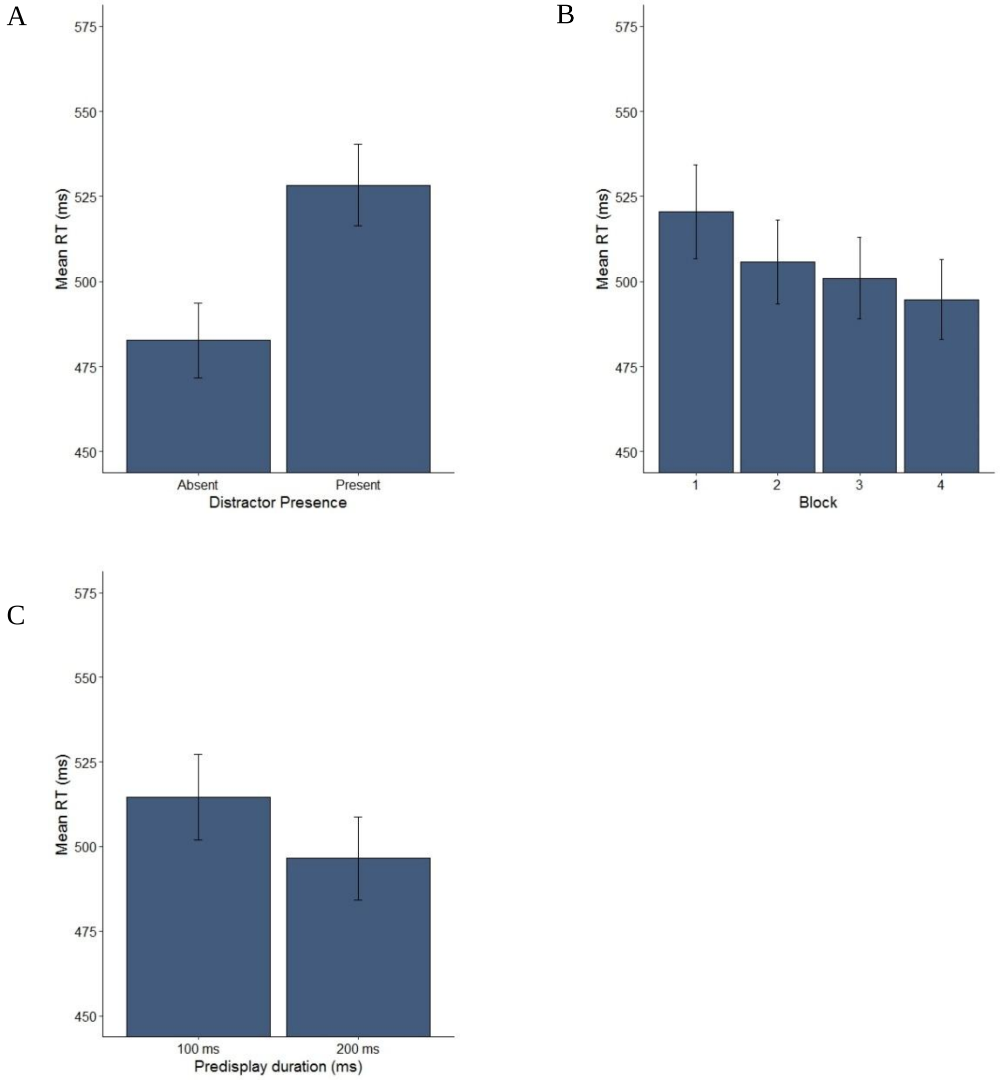


Fig.3 Image absent trials analysis: Main effects. A. Main effect of Distractor Presence. B. Main effect of Block. C. Main effect of Predisplay duration.

The ANOVA revealed, in line with the previous analysis, a significant main effect of Distractor Presence, $F_{(1, 57)}$= 504.86, $p < .001$, ηp2 = .898 (Fig.3 panel a). The salient distractor indeed interfered with the task at hand, thus reflecting again an attentional capture effect (482.68 ms vs. 528.30). The main effect of Block was also significant, $F_{(3, 171)}$= 20.91, $p < .001$, ηp2 = .368, revealing that RTs were faster towards the end of the session (Fig.3 panel b). Also the main effect of Predisplay duration was significant, $F_{(1, 57)}$= 91.09, $p < .001$, ηp2 = .615, showing faster RTs in the longer predisplay interval compared to the shorter one (514.50 ms vs. 496.49 ms) (Fig.3 panel c).

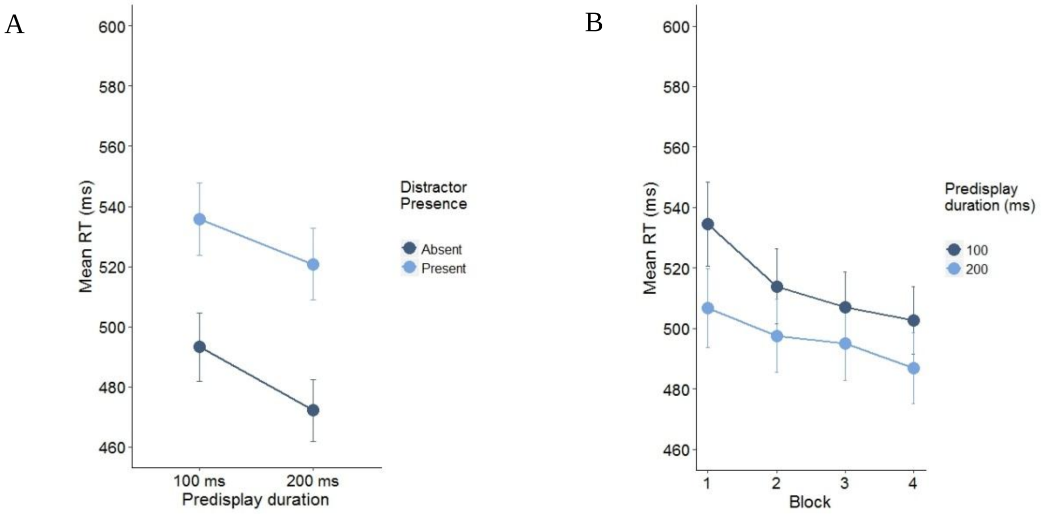


Fig.4 Image absent trials analysis: Interactions between factors. A. Distractor Presence as function of Predisplay duration. B. Predisplay duration as function of Block.

The interaction between Distractor Presence and Predisplay duration was significant, $F_{(1, 57)}$= 4.74, $p = 0.03$, ηp2 = .076 (Fig.4 panel a). Post-hoc t-tests revealed that although the cost due to Distractor presence was significant in both Predisplay duration conditions (Distractor present vs. absent, Predisplay 100 ms: $t_{(239)}$= 19.51, $p < .001$; Predisplay 200 ms: $t_{(239)}$= 22.77, $p < .001$), it was significantly higher in the longer Predisplay interval (Distractor-present vs. Distractor-absent, Predisplay 100 ms, 42.56 ms, vs. Predisplay 200 ms, 48.67 ms; $t_{(239)}$= -2.28, p = 0.02). Moreover, also the interaction between Block and Predisplay reached statistical significance, $F_{(3, 171)}$= 5.74, p < .001 (Fig.4 panel b). RTs were overall slower in the shorter Predisplay condition (100 ms Predisplay duration, Block 1 = 534.42 ms, Block 2 = 513.88 ms, Block 3 = 507.08, Block 4 = 502.63; 200 ms Predisplay duration, Block 1 = 506.69 ms, Block 2 = 497.52 ms, Block 3 = 494.93 ms, Block 4 = 486.80 ms). In this condition however they showed a great improvement across Blocks (100 ms Predisplay duration, Block 1 vs. Block 2: $t_{(119)}$= 5.96, p < .001, Block 2 vs. Block 3: $t_{(119)}$= 2.32, p < .001, Block 3 vs. Block 4: $t_{(119)}$= 1.76, p < .001; 200 ms Predisplay duration, Block 1 vs. Block 2: $t_{(119)}$= 2.40, p = 0.03, Block 2 vs. Block 3: $t_{(119)}$= 0.86, p = 0.38, Block 3 vs. Block 4: $t_{(119)}$= 2.65, p = 0.02) especially in Block 1 (difference between predisplay 100 and 200, Block 1 vs. Block 2: $t_{(119)}$= 2.65, p = 0.008, Block 2 vs. Block 3: $t_{(119)}$= 1.08, p = 0.27, Block 3 vs. Block 4: $t_{(119)}$= -1.09, p = 0.27).

B. Results of the analysis on Reaction Times of Experiment 3

Image present trials

A repeated measures ANOVA was performed on the RTs of responses in the 80% of the trials in which the images were displayed. The factors included, all within subjects, were Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 400 ms).

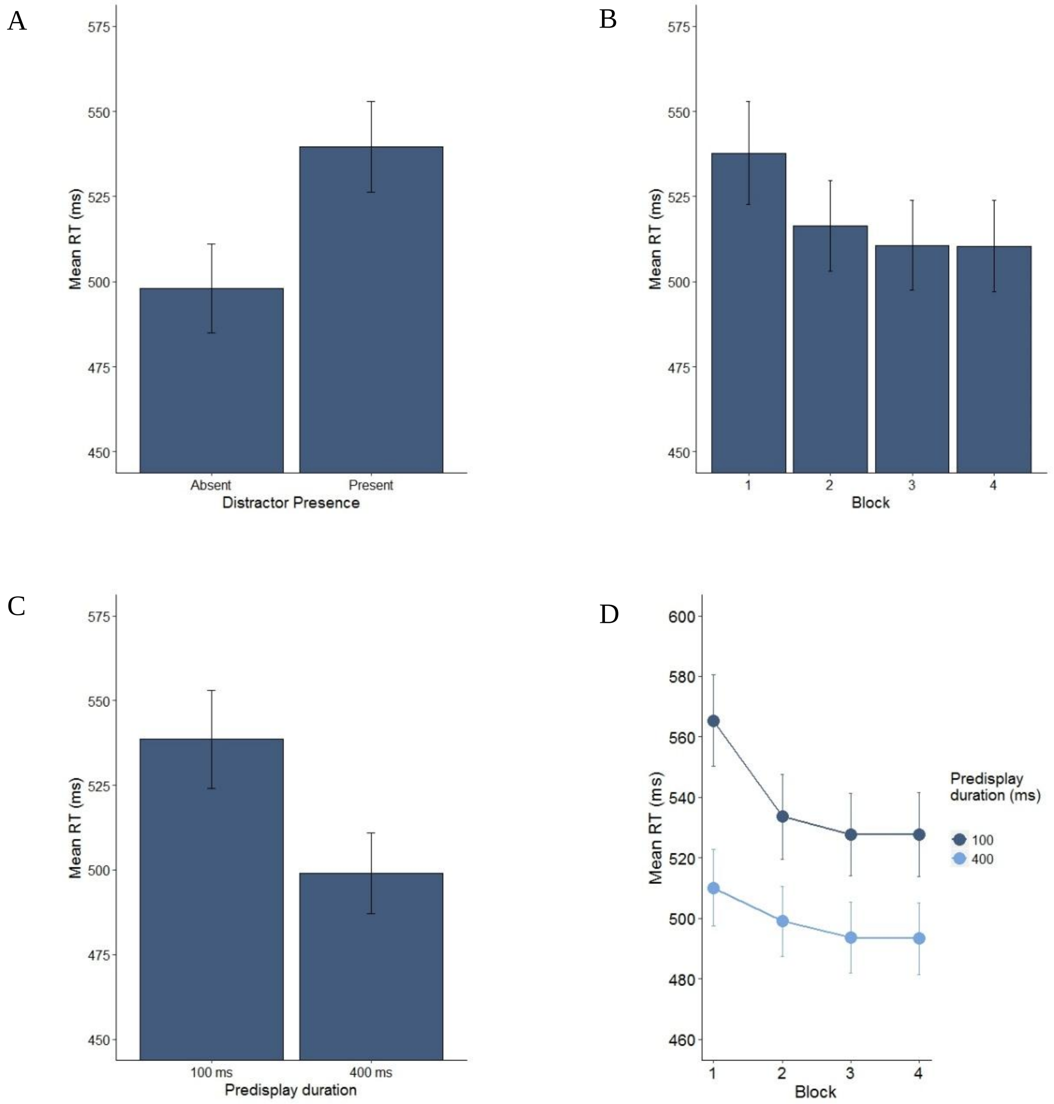


Fig.1 Image present trials analysis. A. Main effect of Distractor Presence. B. Main effect of Block. C. Main effect of Predisplay duration. D. Predisplay duration as function of Block.

The ANOVA yielded a significant main effect of Distractor presence, $F_{(1, 19)}$= 202.86, $p < .001$, ηp2 = .914, reflecting the attentional capture effect with faster RTs in the Distractor-absent condition (498.01 ms vs. 539.56 ms) (Fig.1 panel a). The main effect of Block was also significant, $F_{(3, 57)}$= 10.80, $p < .001$, ηp2 = .504, in fact RTs became faster throughout the session (Fig.1 panel b). Also the main effect of Prediplay duration was statistically significant, $F_{(1, 19)}$= 79.34, $p < .001$, ηp2 = .806 (Fig.1 panel c). RTs were significantly slower in the shorter Predisplay duration (538.56 ms vs. 499.02 ms). The interaction between Block and Predisplay duration was significant as well, $F_{(3, 57)}$= 11.47, $p < .001$, ηp2 = .580 (Fig.1 panel d). While RTs were always significantly slower in the shorter Predisplay duration (100 ms Predisplay duration, Block 1 = 565.40 ms, Block 2 = 533.63 ms, Block 3 = 527.57, Block 4 = 527.62; 400 ms Predisplay duration, Block 1 = 510.09 ms, Block 2 = 498.99 ms, Block 3 = 493.70 ms, Block 4 = 493.28 ms), the improvement across blocks was particularly marked in this condition (100 ms Predisplay duration, Block 1 vs. Block 2: $t_{(39)}$= 7.03, $p < .001$, Block 2 vs. Block 3: $t_{(39)}$= 1.82, p = 0.07, Block 3 vs. Block 4: $t_{(39)}$= -0.01, p = 0.98; 400 ms Predisplay duration, Block 1 vs. Block 2: $t_{(39)}$= 2.59, p = 0.03, Block 2 vs. Block 3: $t_{(39)}$= 1.52, p = 0.27, Block 3 vs. Block 4: $t_{(39)}$= 0.13, p = 0.89), especially in Block 1 (difference between predisplay 100 and 200, Block 1 vs. Block 2: $t_{(39)}$= 4.79, $p < .001$, Block 2 vs. Block 3: $t_{(39)}$= 0.20, p = 0.83, Block 3 vs. Block 4: $t_{(39)}$= -0.15, p = 0.87).

Image absent trials

As usual, a repeated measures ANOVA was also performed on the RTs of responses in the 20% of the trials, in which the images were not shown, and replaced by colored noise. The factors included were Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 400 ms).

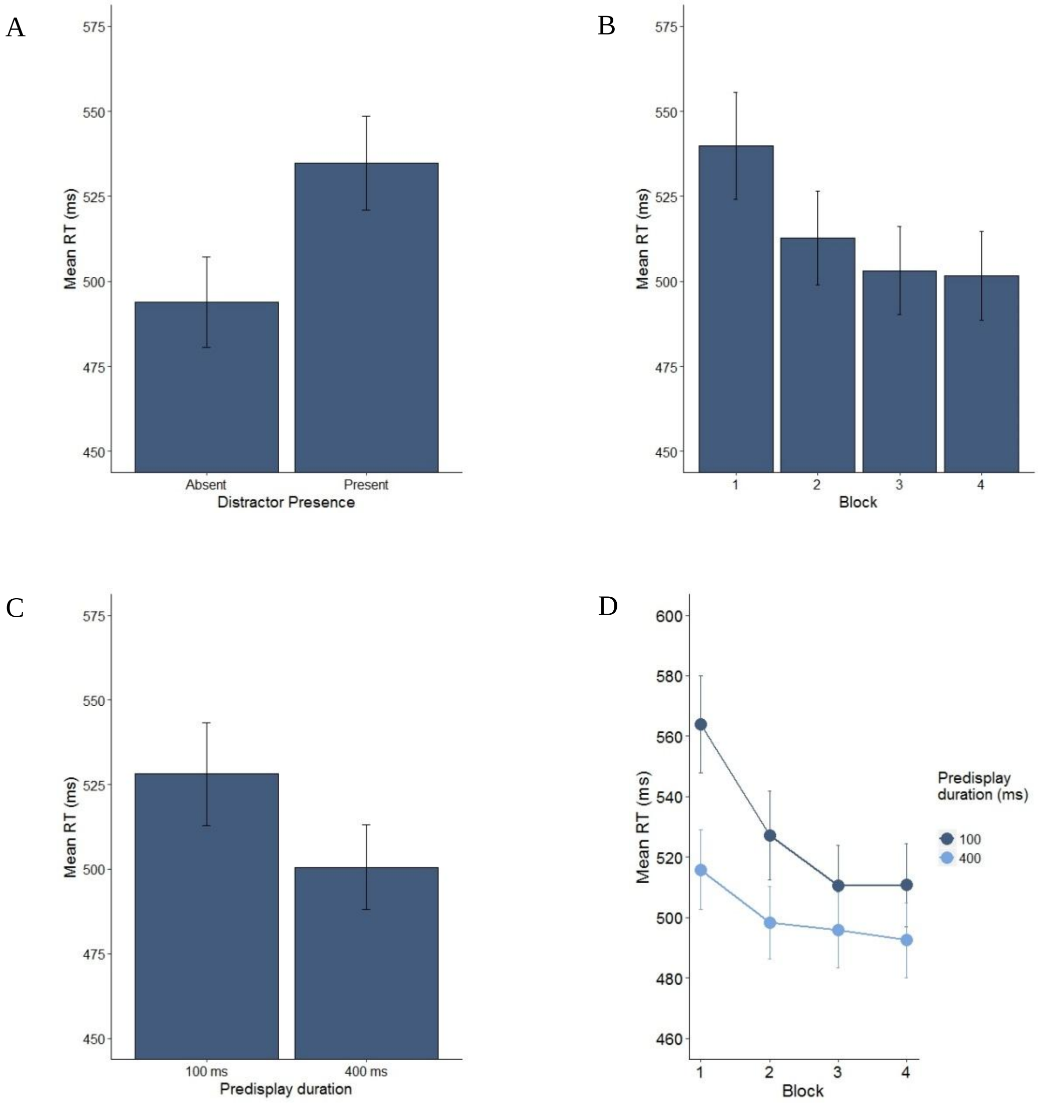


Fig.2 Image absent trials analysis. A. Main effect of Distractor Presence. B. Main effect of Block. C. Main effect of Predisplay duration. D. Predisplay duration as function of Block.

The ANOVA revealed a significant main effect of Distractor presence, $F_{(1, 19)}=108.08$, $p < .001$, ηp2 = .851, confirming the attentional capture effect (493.91 ms vs. 534.74 ms) (Fig.2 panel a). The main effects of Block, $F_{(3, 57)}=16.50$, $p < .001$, ηp2 = .537, and Predisplay duration, $F_{(1, 19)}=51.48$, $p < .001$, ηp2 = .731, were also significant, reflecting faster RTs towards the end of the session (Fig.2 panel b) and significantly faster RTs in the longer Predisplay duration (528.10 ms vs. 500.55 ms) (Fig.2 panel c), respectively. Again, the interaction between Block and Predisplay duration was significant, $F_{(3, 57)}$=7.35, $p < .001$, ηp2 = .446 (Fig.2 panel d). In line with the previous analysis, RTs were slower in the shorter Predisplay duration in all of the four Blocks (100 ms Predisplay duration, Block 1 = 563.94 ms, Block 2 = 527.18 ms, Block 3 = 510.61, Block 4 = 510.68; 400 ms Predisplay duration, Block 1 = 515.73 ms, Block 2 = 498.26 ms, Block 3 = 495.77 ms, Block 4 = 492.44 ms). Again, RTs became faster in both Predisplay conditions, but the effect of Block was more marked for trials with a shorter Predisplay (100 ms Predisplay duration, Block 1 vs. Block 2: $t_{(39)}$= 5.20, $p < .001$, Block 2 vs. Block 3: $t_{(39)}$= 3.72, $p < .001$, Block 3 vs. Block 4: $t_{(39)}$= -0.01, p = 0.98; 400 ms Predisplay duration, Block 1 vs. Block 2: $t_{(39)}$= 2.39, p = 0.02, Block 2 vs. Block 3: $t_{(39)}$= 0.41, p = 0.68, Block 3 vs. Block 4: $t_{(39)}$= 0.68, p = 0.49). Moreover, the difference between the two Predisplay conditions was significantly greater in Block 1 with respect to all the others (difference between predisplay 100 and 200, Block 1 vs. Block 2: $t_{(39)}$= 2.03, p = 0.04, Block 2 vs. Block 3: $t_{(39)}$= 1.90, p = 0.06, Block 3 vs. Block 4: $t_{(39)}$= -0.54, p = 0.58).

C. Results of the analysis on Reaction Times of Experiment 4

Image present trials

A repeated measures ANOVA was carried out on the RTs of responses in the 80% of the trials, in which the images were displayed. The factors included were Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 400 ms).

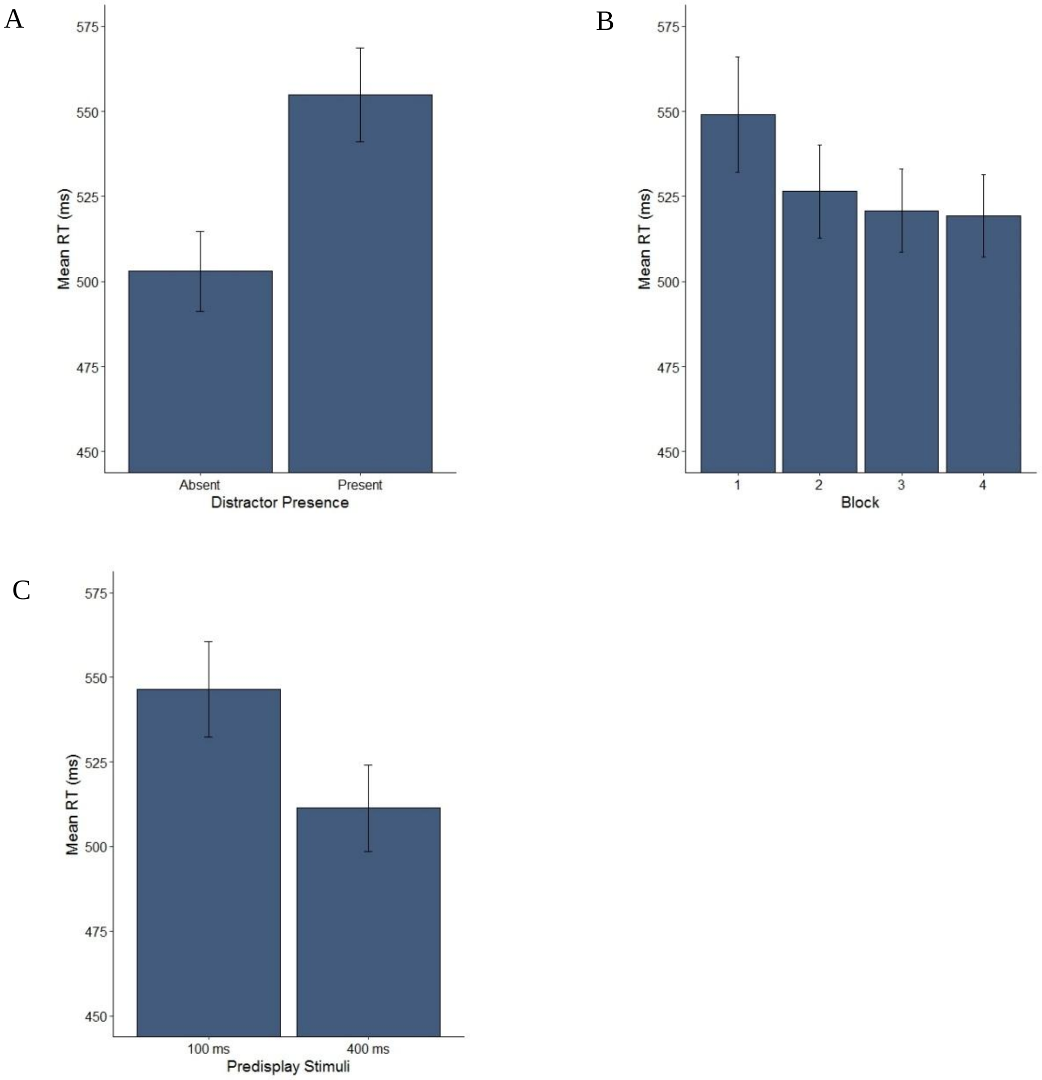


Fig.1 Image present trials analysis: Main effects. A. Main effect of Distractor Presence. B. Main effect of Block. C. Main effect of Predisplay duration.

The ANOVA revealed a significant main effect of Distractor presence, $F_{(1,\ 19)}$= 281.55, p < .001, ηp2 = .936, suggesting that the distractor interfered with the task at hand, reflecting again attentional capture effect (502.97 ms vs. 554.79 ms) (Fig.1 panel a). Results showed also a main effect of Block, $F_{(3,\ 57)}$= 9.84, p < .001, ηp2 = .421, since RTs were faster towards the end of the session (Fig.1 panel b). A main effect of Predisplay duration was found as well, $F_{(1,\ 19)}$= 53.66, p < .001, ηp2 = .738, reflecting, in line with the previous analysis, shorter RTs in the longer Predisplay duration (546.40 ms vs. 511.37 ms) (Fig.1 panel c).

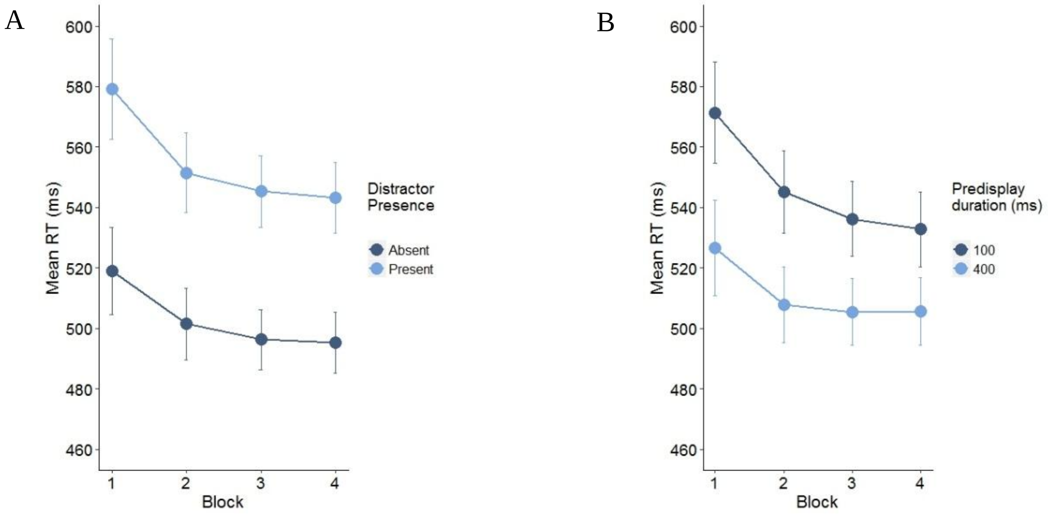


Fig.2 Image present trials analysis: Interaction effects. A. Distractor Presence as function of Block. B. Predisplay duration as function of Block.

The interaction between Distractor Presence and Block was significant, $F_{(3,\ 57)}$= 4.58, p = 0.006, ηp2 = .398 (Fig.2 panel a). RTs were significantly slower in the Distractor-present condition compared to the Distractor-absent condition in all of the four Blocks (Distractor-present vs. Distractor-absent, Block 1: $t_{(39)}$= -16.35, p < .001; Block 2: $t_{(39)}$= -18.48, p < .001; Block 3: $t_{(39)}$= -13.07, p < .001; Block 4: $t_{(39)}$= -14.76, p < .001). However, the cost associated with Distractor presence was significantly modulated by Block. In fact, a significant decrease in distractor cost was found only between Block 1 and 2 (Cost of Distractor, Block 1 vs. Block 2: 60.23 ms vs. 49.98 ms, $t_{(39)}$= 2.62, p = 0.01; Block 2 vs. Block 3: 49.98 ms vs.

49.05 ms, $t_{(39)}$= 0.26, p = 0.79; Block 3 vs. Block 4: 49.05 ms vs. 48.03 ms, $t_{(39)}$= 0.23, p = 0.81) . Also the interaction between Block and Predisplay was significant, $F_{(3, 57)}$= 8.06, p < .001, ηp2 = .543 (Fig.2 panel b). RTs were slower in the shorter Predisplay duration in all of the four Blocks (100 ms Predisplay duration, Block 1 = 571.39 ms, Block 2 = 554.14 ms, Block 3 = 536.22, Block 4 = 532.83; 400 ms Predisplay duration, Block 1 = 526.67 ms, Block 2 = 507.73 ms, Block 3 = 505.39 ms, Block 4 = 505.67 ms) and the difference between the two Predisplay conditions was constant throughout the session (difference between predisplay 100 and 200, Block 1 vs. Block 2: $t_{(39)}$= 1.80, p = 0.07, Block 2 vs. Block 3: $t_{(39)}$= 1.61, p = 0.11, Block 3 vs. Block 4: $t_{(39)}$= 1.01, p = 0.31). Again, in line with the previous analysis, RTs became faster across Blocks in both Predisplay conditions, but the effect was especially marked for trials with a shorter Predisplay duration (100 ms Predisplay duration, Block 1 vs. Block 2: $t_{(39)}$= 5.16, p < .001, Block 2 vs. Block 3: $t_{(39)}$= 2.54 p = 0.01, Block 3 vs. Block 4: $t_{(39)}$= 0.93, p = 0.35; 400 ms Predisplay duration, Block 1 vs. Block 2: $t_{(39)}$= 0.64, p < .001, Block 2 vs. Block 3: $t_{(39)}$= 0.64, p = 0.52, Block 3 vs. Block 4: $t_{(39)}$= -0.07, p = 0.94).

Image absent trials

In line with the other analysis, a repeated measures ANOVA was performed on the RTs of responses in the 20% of the trials, in which the images were not displayed. The factors included were Distractor Presence (present or absent), Block (1-4) and Predisplay duration (100 or 400 ms).

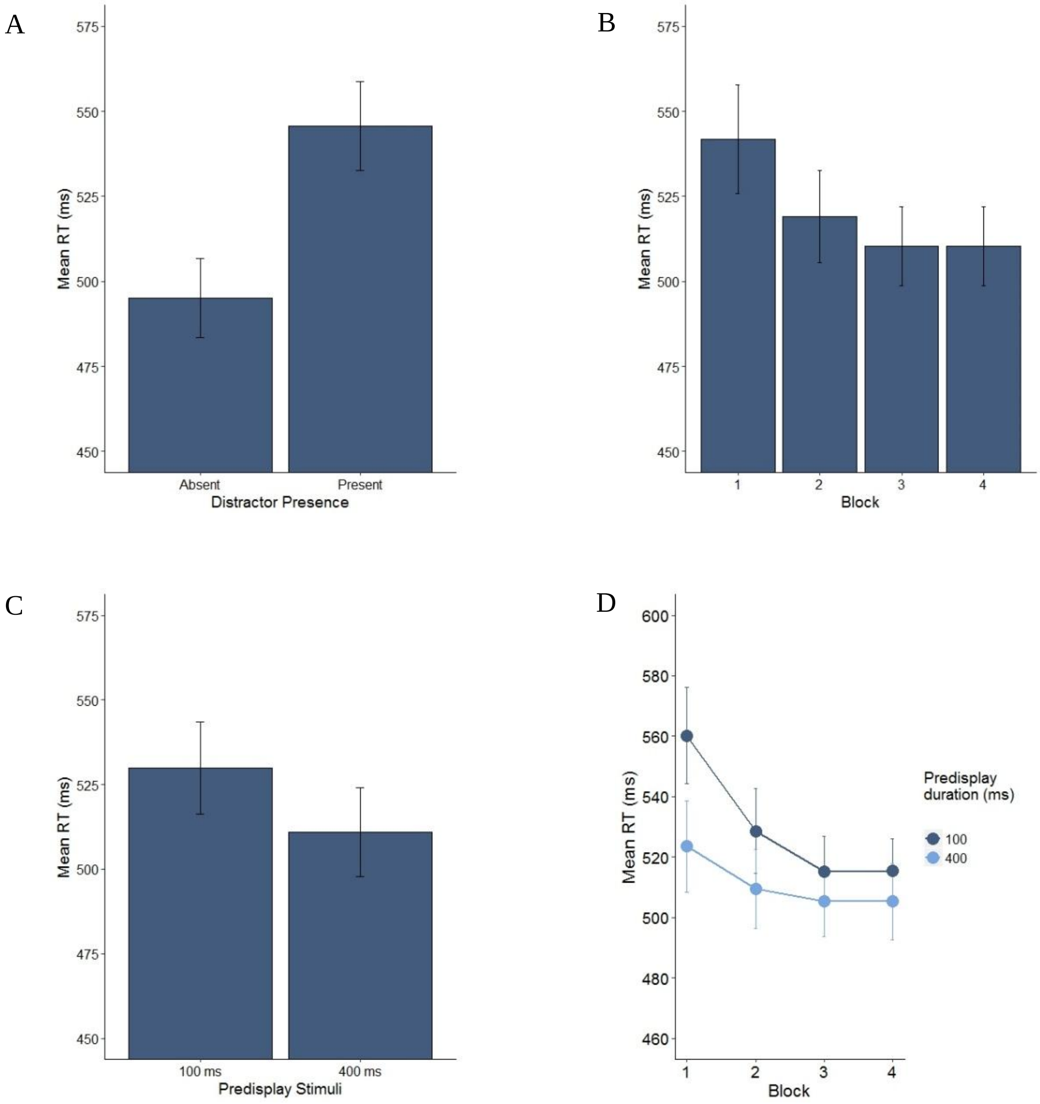


Fig.3 Image absent trials analysis. A. Main effect of Distractor Presence. B. Main effect of Block. C. Main effect of Predisplay duration. D. Distractor Presence as function of Block.

The ANOVA revealed a significant main effect of Distractor presence, $F_{(1,\ 19)}$= 329.68, p < .001, ηp2 = .945, reflecting again the attentional capture effect (495.08 ms vs. 545.72 ms) (Fig.3 panel a). The main effect of Block was also significant, $F_{(3,\ 57)}$= 11.31, p < .001, ηp2 = .536 (Fig.3 panel b). RTs, in fact, were faster towards the end of the session. The main effect of Predisplay duration was also significant, $F_{(3,\ 19)}$= 23.85, p < .001, ηp2 = .556, reflecting slower RTs in the shorter Predisplay duration (529.87 ms vs. 510.93 ms) (Fig.3 panel c). Again, the interaction between Block and Predisplay was significant, $F_{(3,\ 57)}$= 5.96, p = 0.001,

$\eta p2$ = .404, suggesting that although RTs were slower in the shorter Predisplay duration in all of the four Blocks (100 ms Predisplay duration, Block 1 = 560.16 ms, Block 2 = 528.64 ms, Block 3 = 515.20, Block 4 = 515.48; 400 ms Predisplay duration, Block 1 = 523.52 ms, Block 2 = 509.58 ms, Block 3 = 505.40 ms, Block 4 = 505.23 ms), the RT reduction was more evident for trials with a shorter Predisplay (100 ms Predisplay duration, Block 1 vs. Block 2: $t_{(39)}$= 4.89, $p < .001$, Block 2 vs. Block 3: $t_{(39)}$= 2.31 p = 0.02, Block 3 vs. Block 4: $t_{(39)}$= -0.05, p = 0.95; 400 ms Predisplay duration, Block 1 vs. Block 2: $t_{(39)}$= 2.66, p = 0.01, Block 2 vs. Block 3: $t_{(39)}$= 0.92, p = 0.36, Block 3 vs. Block 4: $t_{(39)}$= 0.03, p = 0.97). Moreover, the difference between the two Predisplay conditions was significantly greater in Block 1 (difference between predisplay 100 and 200, Block 1 vs. Block 2: $t_{(39)}$= 2.57, p = 0.01, Block 2 vs. Block 3: $t_{(39)}$= 1.55, p = 0.12, Block 3 vs. Block 4: $t_{(39)}$= -0.06, p = 0.94) (Fig.3 panel d).

General discussion

As already explained in the main text discussing Experiment 2, the main effects of the manipulations at the core of our research interest were crucially revealed by response accuracy. In none of the analyses of RTs were we able to observe a significant modulation of the performance costs due to distractor presence, as a function of either Valence (when it was a factor), Predisplay duration and Block. If anything, we found a systematic, paramount improvement in response speed across all Experiments and conditions, merely reflecting the beneficial impact of practice with the task at hand. The combined impact of emotional images and time on task (further modulated by Predisplay duration) on attentional filtering (i.e., the effect of Distractor presence) was only detectable in accuracy rates. This finding might be explained by the fact that the paradigm required very speeded responses in order to meet a very close deadline, and the massive top-down control on task responses needed to provide such fast responses did not allow space to express any sign of the yet ongoing depletion of attentional resources.

Appendix 2

Movie clip information

Title	Year	Start Time	End Time	Total Time
The NeverEnding Story	1984	0:31:00	0:33:25	2:25
The Green Mile	1999	2:47:50	3:00:40	2:50
Schindler’s List	1993	2:57:50	3:00:40	2:50
My Girl	1991	1:19:56	1:22:30	2:34
Requiem for a dream (https://www.youtube.com/watch?v=TsAYisil5yg)	2000	00:06	2:03	1:57
Antichrist	2009	00:59:25	1:00:52	1:27

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