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PROACTIVE TOP-DOWN PROCESSES IN VISUAL SEARCH

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ABSTRACT

Literature has long investigated the contributions of top-down and bottom-up processes in guiding search behavior. Recent findings suggest a modulatory role of top-down processes on attentional capture. However, results are contradictory, and whether and how top-down processes intervene has not been clearly established yet.

Here, we approached the issue from the perspective of proactive top-down processes of distractor expectation and leveraged the Distractor Context Manipulation (DCM) paradigm to help characterizing their recruitment in visual search. Thus, we combined a feature search (i.e., search for a high-contrast target among no-contrast distractors) and a conjunction search (i.e., search for a high-contrast target among high-contrast distractors) with the DCM paradigm (Exp 1-4). Accordingly, blocks of trials were of three types: a Pure block containing no distractor-present trials, and two blocks containing frequent distractor-present trials (i.e., Mixed Feature and Mixed Conjunction). Subjects were instructed to look for the target on each trial. The comparison of distractor-absent trials of Mixed vs Pure blocks allowed detecting proactive top-down processes of distractor expectation. First, we investigated whether proactive top-down processes were recruited in distracting contexts of visual search and whether their potential recruitment was modulated by the type of search (Exp 1). Results attested for a proactive recruitment of top-down processes of distractor expectation in both feature and conjunction search. Such recruitment entailed a response time (RT) cost as well as a beneficial enhancement of the detection sensitivity (d’) to the target when distractors were expected, yet not presented. Overlapping results emerged in covert (Exp 1, 3) and overt (Exp 2, 4) variants of visual search. Since previous distracting experience shaped distractor expectation, we, also, sought to disentangle the role of expectation

and experience in the activation of top-down processes. Results (Exp 2, 4) showed that the distractor expectation cost occurred regardless of whether or not distractors occurred in the immediately preceding trial. However, the magnitude of the cost was larger after distracting trials suggesting that these processes do not rely only on tonic expectation-based mechanisms but they are also contingently reinstated after a distracting experience occurred. Experiment 3 tried to characterize the implicit vs explicit nature of top-down mechanisms triggered by distracting experience. Results showed that RT-costs and d'-benefits did not change when distraction occurrence was unpredictable and when it was predictable. Therefore, top-down control setting triggered by recent distracting experience seems to be not subjected to explicit control. Experiment 4 further investigated the role of experience and expectations in order to disentangle their relative contributions. Here, also another type of top-down expectation was manipulated: the temporal certainty of incoming potentially distracting event. Results indicated a preponderant role of top-down expectations by showing that RT-costs followed the time course of temporal expectation of incoming potentially distracting events while temporal recency from a previous distracting experience had a smaller weight. Finally, Experiment 4 explored the EEG correlates of distractor expectation. An enhancement of the occipital P1 amplitude was elicited by both search and neutral stimuli but only when a temporal expectation of a potentially distracting event was induced indicating that distractor expectation modulates visual attentional processes in lower sensory areas.

Overall, results suggested that in both feature and conjunction search preparatory top-down processes are proactively enrolled to face with expected task demands based on previous distracting experiences. These results help characterizing how top-down mechanisms intervene in different types of visual search.

CHAPTER 1

INTRODUCTION

1.1 Top-down and bottom-up processes in visual search

In the past 35 years, literature has long investigated the role of top-down and bottom-up processes in guiding behavior (for a review see Muller & Krummenacher, 2006). Bottom-up processes operate on raw sensory information. They allow attention to be shifted toward salient features of potential importance in a fast and involuntary way. In contrast, top-down processes refer to the use of endogenous goals and cognitive strategies. Several sources of information such as prior knowledge or previous experiences are used to generate predictions of what to expect in the environment. Based on these expectations, our cognitive strategies are proactively accommodated to better face with incoming environmental demands (Connor, Egeth, & Yantis, 2004). Visual search task represents the most used and effective paradigm to experimentally investigate how bottom-up and top-down processes interact with each other. Typically, visual search requires participants to look for a target stimulus presented among distractors of variable numerosity. Two methods have been commonly used. In what can be called the covert variant of visual search, the experimenter briefly presents an array of items followed by a mask. Participants are instructed to fixate the center of the screen and eye movements are not allowed. The participant gives a forced-choice, “the target is present”, or “the target is absent” response. In the second method, called the overt variant of visual search, the array of items is typically presented until a response is made, and eye movements are allowed leading to foveation of the attended stimuli.

Typically, response time (or accuracy) as a function of the total number of items (i.e., set-size) is considered. Based on the search slopes (i.e., the slope of the function that relates RT to set size) obtained in a variety of search tasks, classical models proposed a clear distinction between a preattentive parallel and an attentive serial search mode (e.g., Treisman & Gelade, 1980; Neisser, 1967). If response time does not increase with set size, it has been assumed that all items are processed in parallel. A typical example is when the target differs from distractors by a single basic feature (i.e., feature search). The preattentive processing causes attention to be automatically deployed to that item so it is examined before any others (e.g. Treisman and Gelade, 1980; Wolfe, 1994). On the other hand, if response time linearly increases as a function of set size, it has been assumed that attention has been actively and serially deployed to the individual items. The initial idea that searches modes are separated into two classes, attentive serial and preattentive parallel, has not been longer supported by following studies that showed a continuum of search results (Wolfe, 1998). In this regard, Duncan & Humphreys (1989) pointed out that search performances worsen as target-distractor similarity increases. Nagy and Sanchez (1990), for example, demonstrated that the feature search slopes increase as the difference between the target and the distractor colour increases. Over time, the serial/parallel dichotomy has been largely abandoned. More attention has been recently given on how top-down and bottom-up processes interact in guiding search behaviour and one of the most investigated issues consists in whether and how top-down processes can modulate pop-out attentional capture by salient stimuli.

1.2 Top-down modulation of attentional capture

In everyday life, the maintenance of current goals and expectations about upcoming sensory stimuli is crucial for selecting task-relevant information while blocking irrelevant and/or potentially distracting stimuli. Proactive top-down processes allow the anticipatory maintenance of a specific control set in accordance with internally maintained behavioral goals (Braver, Paxton, Locke, & Barch, 2009; Begnoche, 2016). These mechanisms prepare and accommodate our cognitive set in order to be ready to better face with expected task demands. For example, in the context of visual search, when one looks at a crowd searching for a friend that usually wears a red jacket, attention is guided by this top-down expectation. One might direct visual attention sequentially to individuals wearing red clothing and ignore all other colors (see for example the Guided Search Theory for conjunction search tasks; Wolfe, 1994; Wolfe, Cave, Franzel, 1989). However, if the person we are looking for is the only individual within the crowd that wears a red jacket, then finding him would be much faster because of bottom-up saliency. When a visually-salient stimulus is presented in a visual scene, advance knowledge of the specific salient feature (i.e., is our friend wearing a red or a blue jacket?) does not seem to facilitate search further because under such circumstances attention seems to be captured automatically by the most salient stimulus regardless of top-down knowledge. Pure bottom-up functioning may be very efficient when we look to the most salient stimulus in a scene. However, a limitation of this modality is that attention should be continuously and constantly at the mercy of salient stimuli even when these are irrelevant for our purposes. Recently, a growing body of literature seems to suggest a modulatory role of top-down attention on bottom-up capture, when needed. Folk, Remington, and Johnston (1992) have shown that the ability of a stimulus to capture attention is modulated by the subject's top-down attentional state. In their experiment subjects were instructed to look for a color singleton (i.e., a single red target presented among white distractors) or for an onset singleton (i.e., a unique item presented with an abrupt onset). The search display was preceded by an irrelevant color-singleton cue or an onset-singleton cue. Results showed that cue singleton immediately preceding the search display attracted attention in a bottom-up way, affecting response time when they appeared at the same location of the upcoming targets (i.e., responses were slower when the cue appeared at a different location and faster when it appeared at the same location as the upcoming target). However, color-singleton cues only modulated responses when the subject was looking for a color target and onset-singleton cues only modulated responses when the subject was looking for an onset target. Therefore, attentional capture was ineffective when the nature of the cue-singleton was incongruent with that of the target-singleton. These results provided convincing evidence suggesting that top-down attention could modulate attentional capture when we need to look for something specific. Other evidence suggested a top-down involvement in the search for a pop-out target. In these studies, the search for a known feature (i.e., the feature that defined the target remained the same for all trials; e.g., blue) was compared with the search for a variable feature (i.e., the feature that defined the target was unique in each stimulus display, but it changed from trial to trial; e.g., blue, red or white). In either case, the target stimulus was presented within a homogenous array of distractors (e.g., green distractors) (e.g., Treisman, 1988; Wolfe, Butcher, Lee, & Hyle, 2003). Results showed that search for a known feature is faster than search for a variable feature, and this finding seems to support the hypothesis that top-down knowledge plays a role in feature search tasks (Folk, Remington, & Johnston, 1992; Muller, Reimann, Krummenacher. & 2003; Muller, & Krummenacher, 2006; Wolfe et al., 2003). However, these findings are not conclusive. As argued by Theueewes (2006; 2013), the response time modulation observed in these experiments may represent the results of a bottom-up priming of the feature of the target, which occurs when the target is repeated across-trials (Theueewes, 2013). This type of inter-trial facilitation is completely driven by bottom-up processes and it is not subject to the control of top-down processes. The position of Theueewes (2006; 2013) is consistent with the findings of Maljkovic & Nakayama (1994). They showed that predictable changes in the target colour (e.g. alternating red-green-red-green over trials) produced response times that were indistinguishable from unpredictable changes, suggesting that it is impossible to counteract the priming of the target presented in a previous trial. Moreover, Theeuwes in his studies (1992; 2004; 2013) manipulated the salience of target and distractors and provided various evidence of a pure saliency-driven functioning during visual search. For example he demonstrated that the presence of an irrelevant singleton distractor (i.e., an item with a unique feature) slowed down the search for a target singleton when the distractor singleton was more salient than the target singleton but not vice-versa (1992). This result has been interpreted as evidence that attentional capture is entirely driven by salience.

Although a growing body of literature seems to suggest a modulatory role of top-down attention on bottom-up capture when it is needed to counteract negative effects of distractor, results are contradictory, and whether or not top-down processes modulate attentional capture by salient stimuli has not been clearly established yet (Muller & Krummenacher, 2006; Theeuwes, 2013; Connor, Egeth, & Yantis, 2004). Here, we sought out to elucidate this issue by approaching the problem from a different point of view. Differently from the previous studies about how the target feature affect attentional capture (Treisman, 1988; Wolfe, Butcher, Lee, & Hyle, 2003), here, we focused on the distractors defining features. Literature distinguishes three possible preparatory control mechanisms for suppressing distracting information before it is presented: direct inhibition, secondary inhibition, and inhibition by expectation suppression (Noonan, Crittenden, Jensen, & Stokes, 2017). Direct inhibition is conceived as the complementary mechanism to top-down facilitation. Higher-order brain regions (e.g., dorsolateral prefrontal cortex, inferior frontal gyrus, and parietal cortex) would directly and selectively modulate distractor related processing circuits prior to the stimuli presentation. Secondary inhibition, on the other hand, is expressed as a secondary consequence of top-down target facilitation. A complementary spread of inhibition to unattended features is triggered via local inhibitory circuits following the top-down excitation of target-related neural populations in lower sensory areas. This form of inhibition, therefore, should be as flexible and rapid, as target facilitation, but not specific for type of distraction (i.e., it suppresses everything is not relevant). Finally, by means of expectation suppression, each stage of visual processing generates and updates hypotheses about incoming sensory input. Based on these hypotheses a general suppression mechanism would inhibit all repeated and predictable inputs and, at the same time, top-down attention would release task-relevant stimuli from this inhibition.

In this study, we sought to explore how previous knowledge about the distractors defining features affect it. In particular, we tested whether and how top-down processes of distractor expectation are recruited in conjunction search (i.e., when their recruitment would be needed to contrast negative impact driven by expected distractors on performance) and in feature search (i.e., when their recruitment would be irrelevant because of the pop-out effect).

1.3 Studying visual search with the Distracting Context Manipulation paradigm

Imagine now a different context, the driving. Typically, important road signs (e.g., the red traffic light) has been designed to be as much salient as possible to capture your attention. Moreover, these stimuli are relevant according to the driver goals. At the same time, the driver needs to ignore several other irrelevant stimuli that he/she expects to meet along his/her way (e.g., shop signs or billboards on the side of the street). The driving context represents a classic example in which the relevant stimulus is also the one that captures your attention (i.e., search for a pop-out feature). In these situations, the expectation of such type of irrelevant stimuli does affect the driving? Recent studies (Marini, Chelazzi, & Maravita et al., 2013; Marini, van den Berg, & Woldorff, 2015; Marini, Demeter, Roberts, Chelazzi, & Woldorff, 2016) demonstrated that distractor-expectation significantly affect behaviors. In potentially distracting context preparatory top-down processes are proactively invoked in order to limit the negative impact of distracting items. The effects of this recruitment consisted of a beneficial reduction of distractor interference but, also, a simultaneous slowing down when distracting stimuli were expected but not presented. To date the proactive slowing down induced by distractor expectation has been revealed by means of the Distraction Context Manipulation (DCM) paradigm, a method recently introduced to investigate proactive and reactive processes for dealing with task-irrelevant distractor stimuli. This paradigm has been combined with various unimodal (e.g. arrow flanker task) and multimodal (e.g. crossmodal congruency task) selective attention tasks (Marini et al., 2013; 2015; 2016). In these conditions, attentional processing of incongruent stimuli has a negative impact on performances because determine a conflict at response level. Thus, the recruitment of proactive top-down processes for distractor suppression in these types of task is clearly effective to selectively draw attention away from conflicting input. Different is the example of driving described above. In this situation, the attention does not need to be actively guided: being attentional capture and top-down goals congruent, attention should be automatically captured by the relevant stimuli.

In such conditions, are proactive top-down processes of distractor expectation recruited anyway and impact the driver's behavior? Proponents of a pure stimulus-driven mode would probably answer negatively. If top-down processes cannot override attentional capture when a singleton-distractor interferes with performance, there are even fewer reasons to expect their interference when fast attentional capture is beneficial. Nevertheless, even assuming that top-down processes could potentially modulate attentional capture, it is still possible that in these conditions top-down control is withdrawn permitting any relevant target to capture bottom-up attention. Alternatively, that would mean that the mere expectation for distractor automatically determines their recruitment. If this is the case, that would raise other relevant questions. How does their recruitment affect behaviors? How does target-distractors similarity modulate their recruitment? Is this recruitment under volitional control? Which are the relative contributes of recent distracting experience and distractor expectations in their recruitment? How does distractor-expectation modulate visual attentional processes in these contexts?

In the following chapters, we sought out to answer all these questions by combining visual search and Distraction Context Manipulation (DCM) paradigm (Marini, Chelazzi, & Maravita et al., 2013; Marini, van den Berg, & Woldorff, 2015; Marini, Demeter, Roberts, Chelazzi, & Woldorff, 2016). DCM paradigm typically comprises a Pure block, including only distractor-absent trials, and Mixed blocks, including both distractor-absent trials and distractor-present trials. Studies with the DCM paradigm demonstrated that the expectation of task-irrelevant distractors, induced by the occurrence of distractor-present trials in the Mixed blocks, may lead to the recruitment of sustained processes that help to filter out these distractors. As described above, the behavioral signature of such recruitment is a slowing-down of responses in distractor-absent trials, especially when distractor-present trials are presented relatively often within an experimental block. Therefore, this approach has proven particularly useful to elucidate top-down processes involved in the expectation and filtering out of irrelevant distractors across several different cognitive tasks and contexts. Here, we were interested in understanding the extent to which top-down processes intervene in different types of visual search for dealing with expected distractors. Thus, we leveraged the capability of the DCM paradigm to elucidate top-down processes relative to the expectation and filtering-out of task-irrelevant distractors by using this paradigm in two visual search tasks: a feature search task for a salient target stimulus (i.e., a stimulus with high local contrast presented among distractor stimuli with no local contrast) and a conjunction search task in which both the target stimulus and distractors had the same saliency (i.e., the same level of local contrast). Accordingly, blocks of trials were of three types: a Pure block including only distractor-absent trials, and two Mixed blocks (Mixed Feature block and Mixed Conjunction block) including both frequent distractor-present trials and infrequent distractor-absent trials. In each type of search block, participants had to find the target while ignoring irrelevant distractors (if present at all). In line with previous work (Marini, 2013; Marini, 2015; Marini, 2016), we expected that the recruitment of top-down mechanisms related to the expectation and minimization of visual distraction would be indicated by a slowing down of responses on those trials in which distractors were expected but not presented (i.e., distractor-absent trials of the Mixed blocks). Moreover, by quantifying the magnitude of this distractor-expectation cost on performance in different type of search tasks, we investigated if this putative cost was modulated by task-specific attentional demands – as indicated, for example, by larger distractor-expectation costs in the (more demanding) conjunction search task relative to the (less demanding) feature search task.

EXPERIEMENTAL SECTION

CHAPTER 2

EXPERIMENT 1:

PROACTIVE TOP-DOWN CONTROL IN COVERT VISUAL SEARCH

Chapter adapted from:

Petilli, M.A., Marini, F., & Daini, R., (*in preparation*). Proactive Top-Down Mechanisms in visual search.

2.1 Introduction

This experiment assessed whether any preparatory top-down mechanism is proactively recruited during feature and conjunction search to deal with expected distractors. For this purpose, in this experiment visual search and DCM paradigm (Marini et al., 2013; 2015; 2016) were combined. Accordingly, the experiment included three visual search block types: a Pure search block, a Mixed Feature search block, and a Mixed Conjunction search block. Participants' task was to judge as quickly and as accurately as possible the presence or absence of a target while ignoring irrelevant distractors (if present at all). Target stimulus consisted of a stimulus with high local contrast while distractors consisted of no local contrast disks in the Mixed Feature block and disks with high local contrast in the Mixed Conjunction block. Target-present trials included arrays with the target presented by itself or together with other distracting stimuli. Target-absent trials included array without any stimulus or array with only distractors. The Pure search block consisted of 100% distractor-absent trials. The Mixed Feature and the Mixed Conjunction search blocks consisted of ~67% distractor-present trials and ~33% distractor-absent trials. Therefore, in the Pure block, no expectation of distraction was induced in the participants since this block did not comprise trials with distractors. On the contrary, in the Mixed Feature and in the Mixed Conjunction blocks, the expectation of distraction was drawn by the continuous occurrence of distractor-present trials in addition to distractor-absent trials.

As revealed in previous studies having applied DCM paradigm (Marini et al., 2013; 2015; 2016), the comparison between RT of distractor-absent trials of Mixed versus Pure blocks would allow to reveal the proactive RT-cost related to the engagement of preparatory top-down mechanisms for filtering out expected distractors. Therefore, we predicted that, if top-down mechanisms are proactively recruited to minimize visual distraction, we should observe slower RTs when distractors are expected, but not presented, relative to when distractors are neither expected nor presented. Alternatively, if no difference emerges among these conditions, we could not conclude that proactive top-down mechanisms for distraction filtering are engaged in these types of tasks. Moreover, the comparison between RTs when distractors are expected but not presented of the Mixed Feature and the Mixed Conjunction blocks should allow us to highlight whether proactive top-down mechanisms vary according to the attentional demand. If so, we should expect a higher RT-cost caused by the distraction expectation in the Mixed Conjunction block (vs Mixed Feature block), which is known to require a major attentional support for the target selection.

Moreover, we also assessed whether proactive top-down mechanisms modulate the observer's detection sensitivity (d') to counteract the negative impact of distractors. In fact, previous studies indicated that prior knowledge of the target-defining feature influences the sensitivity to the target by enhancing the firing rate of visual neurons that are selective for the attended feature (e.g. Serences, & Boynton, 2007). Therefore, if some proactive top-down process is recruited to enhance the sensitivity to the target when distractors are expected we might observe an increase of d’ when distractors are expected but not presented relative to when distractors are neither expected nor presented.

2.2 Methods

2.2.1 Participants

Twenty-four healthy students at the University of Milano-Bicocca participated in the experiment (5 males, 19-39 years old, mean 24.3 years, SD: 4.1, 22 right-handed). An a priori power analysis was conducted in order to estimate the minimum sample size (using G Power 3.1; Faul, Erdfelder, Lang, & Buchner, 2007). With an α =.05 and power = .8, the projected sample size needed to detect a medium effect size (*f*=.3) is N= 20 for a within-subject ANOVA. The precise number of 24 participants was chosen in all the experiments included in this study in order to completely counterbalance the conditions of target orientation (2 possible conditions), order of blocks (6 possible orders) and key-response correspondence (2 possible alternatives)._Two participants were excluded because of near-chance responses in one experimental condition (error rates: 47% and 48%, respectively). Participants volunteered to take part in the experiment in exchange for course credit. All participants had normal or corrected-to-normal vision.

2.2.2 Equipment

Stimuli were presented on a 20’’ computer screen (Samsung Syncmaster 1200, resolution 1280 x 1024 pixels, 85Hz). A chinrest was used to minimize head movements. The experimental routine was written with the Psychophysics Toolbox 3 (Pelli, 1997; Kleiner, et al., 2007) for Matlab R 2013a (Mathworks Inc.). Participants’ responses were collected through button presses on a standard computer keyboard with Italian layout.

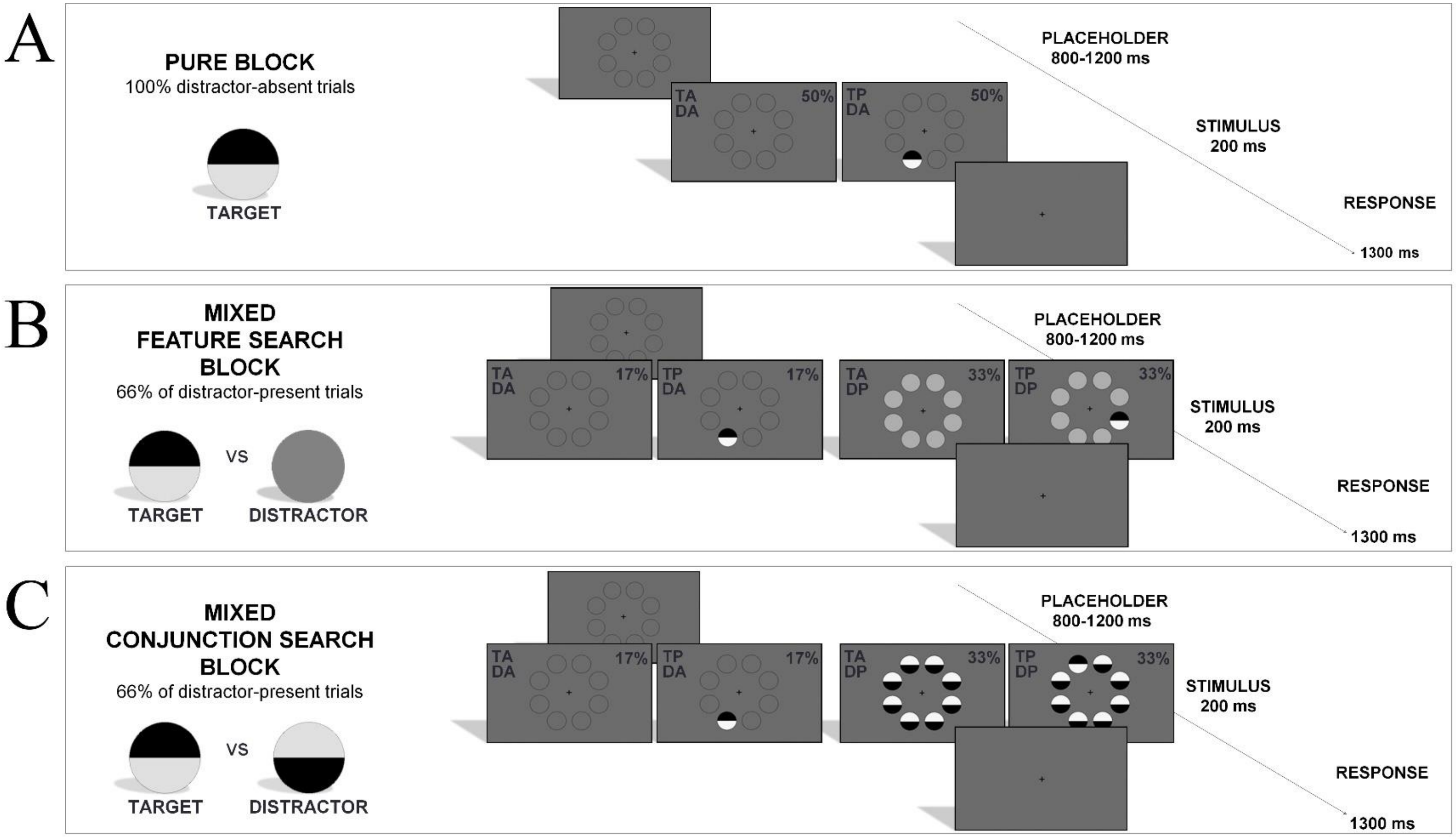

Figure 2.2.1 Schematic representation of the experimental timeline for the three blocks of Experiment 1: Pure search block (Panel A), Mixed Feature search block (Panel B) and Mixed Conjunction search block (Panel C).
Note: TP-DA = Target Present-Distractor-Absent; TA-DA = Target Absent-Distractor Absent; TP-DP = Target Present-Distractor-Present; TA-DP = Target Absent-Distractor Present.

2.2.3 Materials

In each block (i.e., Pure, Mixed Feature, and Mixed Conjunction block), stimulus display could contain arrays without any stimulus (Target-Absent and Distractor-absent trials: TA-DA) and arrays with target presented alone (Target-Present and Distractor-absent trials: TP-DA). Moreover, in the Mixed Feature and Mixed Conjunction blocks display could also contain arrays with 1 target and 7 distractors presented at the same time (Target-Present and Distractor-present trials: TP-DP), and arrays with 8 distractors and no target (Target-Absent and Distractor-present trials: TA-DP). In all trials, each item was arranged circularly around a central fixation cross (radius of search array of 5 degrees of visual angle) at any of 8 possible positions. Throughout the experiment the target stimulus was a horizontally bisected disk with black (mean luminance of 0.11 cd/m2; stimulus/background luminance contrast 0.95%) and light grey (mean luminance of 34.90 cd/m2; stimulus/background luminance contrast 0.94%) halves (i.e., the upper half of the disk was black, and the lower half was light gray, or vice-versa) (luminance contrast between the two halves of the stimulus 99%). In the Mixed Feature block distractors were disks of a single color (middle gray; mean luminance of 5.91 cd/ m2; stimulus/background luminance contrast 0.67%). In the Mixed Conjunction block distractors were represented by horizontally bisected disks whose colors were the same but in reversed position relative to the target stimulus (i.e., the upper half of the disc was light gray, and the lower half was black, or vice-versa) (see **Figure 2.2.1**).

The distance between adjacent stimuli remained fixed across trials (arc-length of 3.9 degrees). All stimuli subtended a visual angle of 2 degrees and were presented on a dark gray background (mean luminance of 1.92 cd/m2).

2.2.4 Design and Procedure

Each block included 50% target-absent trials (TA: all TA-DA in Pure blocks; TA-DA and TA-DP in Mixed blocks) and 50% target-present trials (TP: TP-DA in Pure blocks; TP-DA and TP-DP in Mixed blocks). In Mixed blocks, distractor-present trials (DP: TP-DP and TA-DP) occurred twice as often as distractor-absent trials (DA: TP-DA and TA-DA), thus resulting in a ~33% frequency of DA trials and ~67% frequency of DP trials. Each block was repeated twice (the order was counterbalanced across participants). Pure blocks comprised 48 trials each while Mixed Feature and Mixed Conjunction blocks comprised 144 trials each. The sequence of the trials within each block was randomized.

For the entire duration of the experiment, participants sat in a darkened room with their eyes at a distance of 57 cm from the center of the computer screen.

Prior to the beginning of each block, participants were cued about the type of upcoming block (no distractor, feature, or conjunction). Each block began with 32 practice trials.

Each trial began with the presentation of a central fixation cross and a placeholder display consisting of an array of 8 empty circles (placeholders) indicating the possible positions of appearance of the stimuli. After a variable delay (800 – 1200 ms, randomly drawn from a uniform distribution) the search array was displayed for 200 ms, followed by a blank screen (until response). The inter-trial interval had a duration of 1300 ms (see **Figure 2.2.1**). Subjects were instructed to maintain central fixation throughout the experiment. The task was to ignore any distractors (if present) and to respond as quickly and as accurately as possible by pressing “B” with their right middle finger if the target was present and “V” with their right index finger if the target was absent on the computer keyboard (stimulus-response mapping was counterbalanced across participants). Short breaks were given once every 48 trials.

2.2.5 Data analysis

In the first set of analyses, the measure of RT was used as dependent variable. Trials with RTs faster than 200 ms (anticipatory responses) and/or exceeding the third quartile plus 1.5 interquartile ranges (delayed responses) were eliminated (Ratcliff, 1993). Trials following errors were excluded from the RT analysis to avoid potential confounding effects of post-error slowing (Botvinick, Braver, Barch, Carter, & Cohen, 2001).

Statistical comparisons were conducted with repeated-measure analyses of variance (ANOVA). When significant ANOVA main effects and/or interactions emerged, they were further explored with one-sample t-test or paired-sample t-tests using a false discovery rate (FDR) correction for multiple comparisons (Benjamini & Hochberg, 1995).

In order to analyze the effect of distractor-expectation on detection sensitivity (d') and response bias (B), calculations derived from Signal Detection Theory (SDT) were performed on DA trials (TP-DA and TA-DA trials), separately for each type of block. Values of Hit and False-Alarm rates of 0 or 1 were replaced respectively with 0.5/n and with (n-0.5)/n (where n is the number of trials) (Macmillan & Kaplan, 1985). Measures of d’ were not normally distributed because of a high proportion of ceiling performance. This led to skewed distributions for which the log or square root transformations (e.g., Delucchi, & Bostrom, 2004) did not improve normality. Thus, for the d’ measures of DA trials, non-parametric analyses were conducted (Friedman ANOVA). Accordingly, pairwise comparisons were conducted with the Wilcoxon test (false discovery rate-corrected).

To investigate potential trial-to-trial modulations of the observed RT-cost in presence of expectation for distractors, RTs on DA trials of the Mixed Feature and Mixed Conjunction blocks were sorted according to the type of preceding trial (DP or DA). Because only few TP-DA trials were preceded by another TP-DA trial (~16% of the total), RTs of TP and TA trials were combined for this analysis.

Statistical analyses were performed with IBM SPSS Statistics 23.

2.3 Results

2.3.1 Reaction Times

The first set of analyses assessed proactive top-down processes by comparing TP-DA trials of the three blocks. A one-way ANOVA was conducted on TP-DA trials with the 3-level factor Type of Block (Pure, Mixed Feature, Mixed Conjunction) and identified a significant main effect (F (2, 42) = 29.321, p < .001) (**Figure 2.3.1 A**). Post-hoc analyses revealed that the difference in RTs between DA trials of the Mixed blocks and DA trials of the Pure block was significantly higher than zero both in the Mixed Feature (t (21) = -3.165, p = .016) and in the Mixed Conjunction (t (21) = -6.800, p < .001) blocks, indicating that both conditions incur on a RT-cost on TP-DA trials caused by distractor-expectation. In addition, the RT-cost was significantly higher in the Mixed Conjunction block compared to the Mixed Feature block (t (21) = -4.939, p < .001), suggesting that the effects of distractor-expectation are not ‘all or nothing’ but are modulated by the type of search task (**Figure 2.3.1 B**)

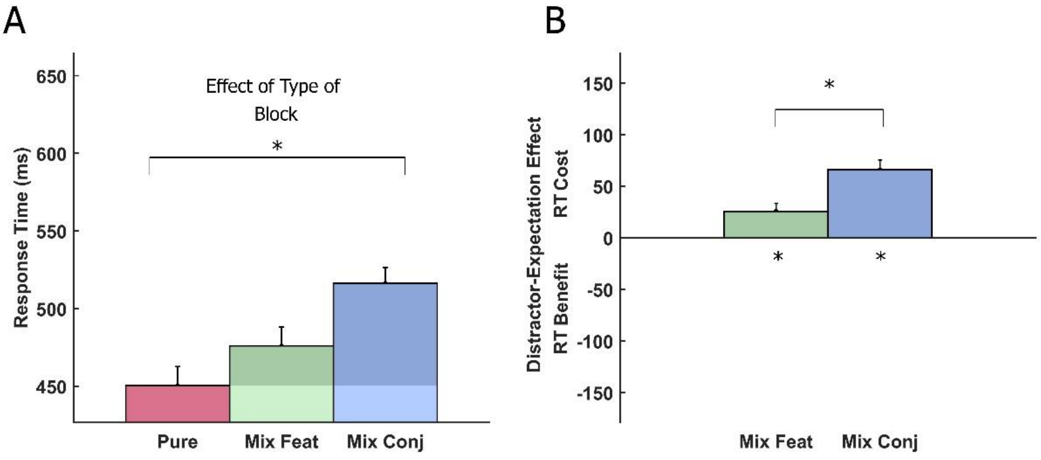

Figure 2.3.1: Response Time (RT) results for Experiment 1.

A) The graph shows RTs for Target-Present and Distractor-Absent trials (TP-DA) of the three blocks (i.e., Pure, Mixed Feature, Mixed Conjunction).

B) The graph shows the effect of distractor-expectation on RTs in Target-Present and Distractor-Absent trials (TP-DA) of the Mixed Feature and Mixed Conjunction blocks (i.e., the difference in RTs between TP-DA trials of the Mixed blocks and TP-DA trials of the Pure block).

Asterisks represent the comparison statistically significant (* p < 0.05). Error bars represent standard error.

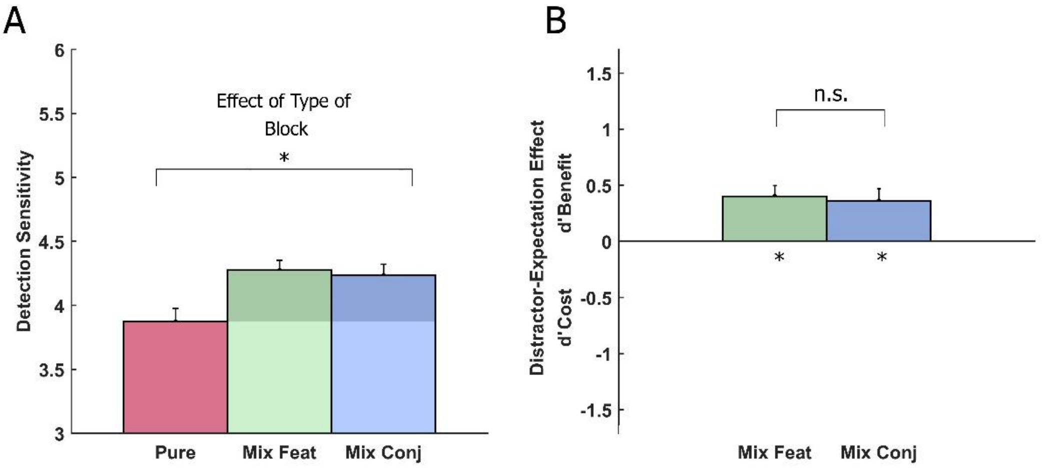

Figure 2.3.2: A) Detection results for Experiment 1.

A) The graph shows d’ for Distractor-Absent trials (TP-DA and TA-DA) of the three blocks (i.e., Pure, Mixed Feature, Mixed Conjunction).

B) The graph shows the effect of distractor-expectation on detection sensitivity (d’) in Distractor-Absent trials (TP-DA and TA-DA) of the Mixed Feature and Mixed Conjunction blocks (i.e., the difference in d’ between DA trials of the Mixed blocks and DA trials of the Pure block).

Asterisks represent the statistically significant comparison (* p < 0.05). Error bars represent standard error.

2.3.2 SDT measures

In order to assess context-dependent changes in detection sensitivity, a Friedman test was conducted with Type of Block as a 3-level factor (Pure, Mixed Feature, Mixed Conjunction) and showed a significant effect ($\chi2$ (2, 22) = 16.575, $p < .001$) (**Figure 2.3.2 A**). Then, we compared the d’ values for each type of Mixed block against d’ for the Pure block. Post-hoc One-Sample Wilcoxon Signed Rank tests showed that the difference in d’ between the Mixed blocks (i.e., Feature and Mixed Conjunction blocks) and the Pure block were significantly higher than zero (all $p < .002$), indicating that distractor-expectation determines a benefit in DA trials of both Mixed blocks. However, no significant difference emerged between d’ of the two types of Mixed blocks ($Z = -0.260$, $p > .99$) (**Figure 2.3.2 B**), suggesting that the distractor-expectation effects do not change as a function of task demands.

Potential changes in response criterion on DA trials of the three types of blocks were evaluated with a repeated-measure ANOVA factoring Type of Block (Pure, Mixed Feature, Mixed Conjunction). No significant result was found (F (2, 42) = 0.528, $p = .594$). Finally, the potential occurrence of response biases was evaluated by comparing response criterion values for each type of block against zero with one sample t-tests. No significant effects were observed (all ps > .173).

2.3.3 Previous trial modulation of RT

In order to investigate potential trial-to-trial modulations of the observed RT-cost (see paragraph 2.3.1), a 2 x 2 ANOVA was conducted with factors Type of Block (Mixed Feature and Mixed Conjunction) and Previous Trial Distractor Presence (DA and DP). This analysis revealed a main effect of Previous Trial Distractor Presence (F (1, 21) = 49.423, p< .001). RT-cost on DA trials following DP trials were higher than RT-cost on DA trials following another DA trial. The effect of Type of Block was significant (F (1, 21) = 19.117, p < .001) indicating that the RT-cost induced by distractor-expectation was enhanced in Mixed Conjunction compared to Mixed Feature block. No significant interaction was observed (F (1, 21) = 0.682, p=0.418), suggesting that the effect of the presence of distractors in the previous trial does not

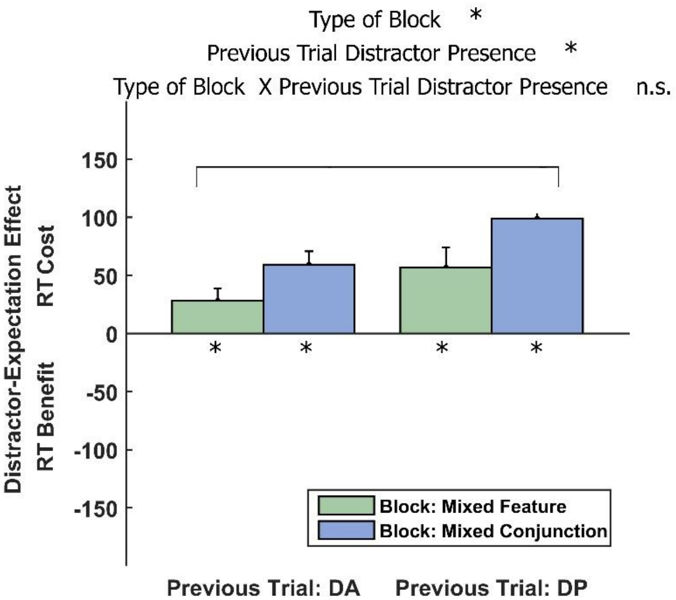

Figure 2.3.3: RT-cost as a function of Type of Block and Previous Trial Distractor Presence for Experiment 1.

The graph shows distractor-expectation RT-costs for Distractor-Absent trials (DA: TP-DA and TA-DA) of the Mixed Feature and Mixed Conjunction blocks (i.e., the difference in RTs between DA trials of the Mixed blocks and the Pure block) separated for DA trials preceded by another DA trial and DA trials preceded by a DP trial (i.e., distractor-present, DP: TP-DP and TA-DP).

Asterisks represent the comparison statistically significant (* p < 0.05). Error bars represent standard error.

differ between Mixed Feature and Mixed Conjunction block. Therefore, these results indicate that the RT-cost observed in DA trials of Mixed blocks was higher in Mixed Conjunction than Mixed Feature block and it was enhanced by the presence of distractors in the previous trials (**Figure 2.3.3**). Finally, in order to evaluate whether the RT-costs were present in all the conditions, we compared the RT-costs of both Mixed blocks against zero with one sample t-tests. As illustrated in **Figure 2.3.3**, these analyses revealed that all the distractor-expectation costs were significantly higher than zero (all $p < .02$).

This pattern of results indicates that the RT-cost caused by distractor expectation likely depends on tonic mechanisms that are sustained throughout the potentially distracting sessions and also contingently reinstated after distractors occurred in a given trial.

2.4 Discussion

Experiment 1 revealed that in distractor-absent trials responses were slower when distractors were expected relative to when distractors were not expected, in line with previous studies (Marini et al., 2013; Marini et al., 2015; Marini et al., 2016). The magnitude of this RT-cost was smaller in the Mixed Feature block and larger in the Mixed Conjunction block. Moreover, Experiment 1 showed that the expectation of distractors was associated with an increase of detection sensitivity that does not depend on the specific type of search context.

However, some specific aspects of the experimental design might have played a role in the observed effects. A previous study (Marini et al., 2016) showed that temporal parameters of the task could be critical for the recruitment of proactive top-down processes. As Marini et al. (2016) pointed out, proactive top-down costs have been typically observed in conditions of sustained cognitive effort. Instead, when the DCM paradigm was applied to a flanker task with slow pace of presentation of the trials, it failed to reveal the typical filtering cost that emerged when a fast pace of presentation of the trials is adopted. The most critical temporal parameter in visual search is the stimulus duration: as Palmer (2011) pointed out, the debates about processes that underlie visual search have often been complicated by differences in stimulus exposure (short exposure of covert tasks vs unlimited exposure of overt tasks). Here, one could argue that results obtained in Experiment 1 cannot be generalized to overt variants of visual search since the time pressure induced by the short stimulus duration of covert tasks might have forced the subjects to adopt a preparatory strategy in order to be ready for discriminate the target stimulus from distractors in the short time available. Therefore, Experiment 1 leaves open the following question: are such proactive processes recruited also in absence of stricter temporal demands on target selection? To deal with this issue, in Experiment 2, we applied the DCM paradigm to an overt visual search task.

CHAPTER 3

EXPERIMENT 2:

PROACTIVE TOP-DOWN CONTROL IN OVERT VISUAL SEARCH

Chapter adapted from:

Petilli, M.A., Marini, F., & Daini, R., (*in preparation*). Proactive Top-Down Mechanisms in visual search.

3.1 Introduction

Experiment 2 investigated the recruitment of proactive top-down mechanisms when the task is performed without time pressure and in presence of an overt search strategy. Specifically, unlimited time was allotted for the response, eye movements were allowed, and the search array stayed on-screen until a response was made. If proactive top-down mechanisms in visual search are engaged in overt search with no time pressure, then the results of this experiment should replicate those of Experiment 1, i.e. slower RTs when distractors were expected (yet not presented) relative to when distractors were neither expected nor presented. Alternatively, if no distractor-expectation RT-cost would emerge, then we should conclude that the different search characteristics of Experiment 2 impacted the recruitment of proactive top-down mechanisms in visual search differently from Experiment 1.

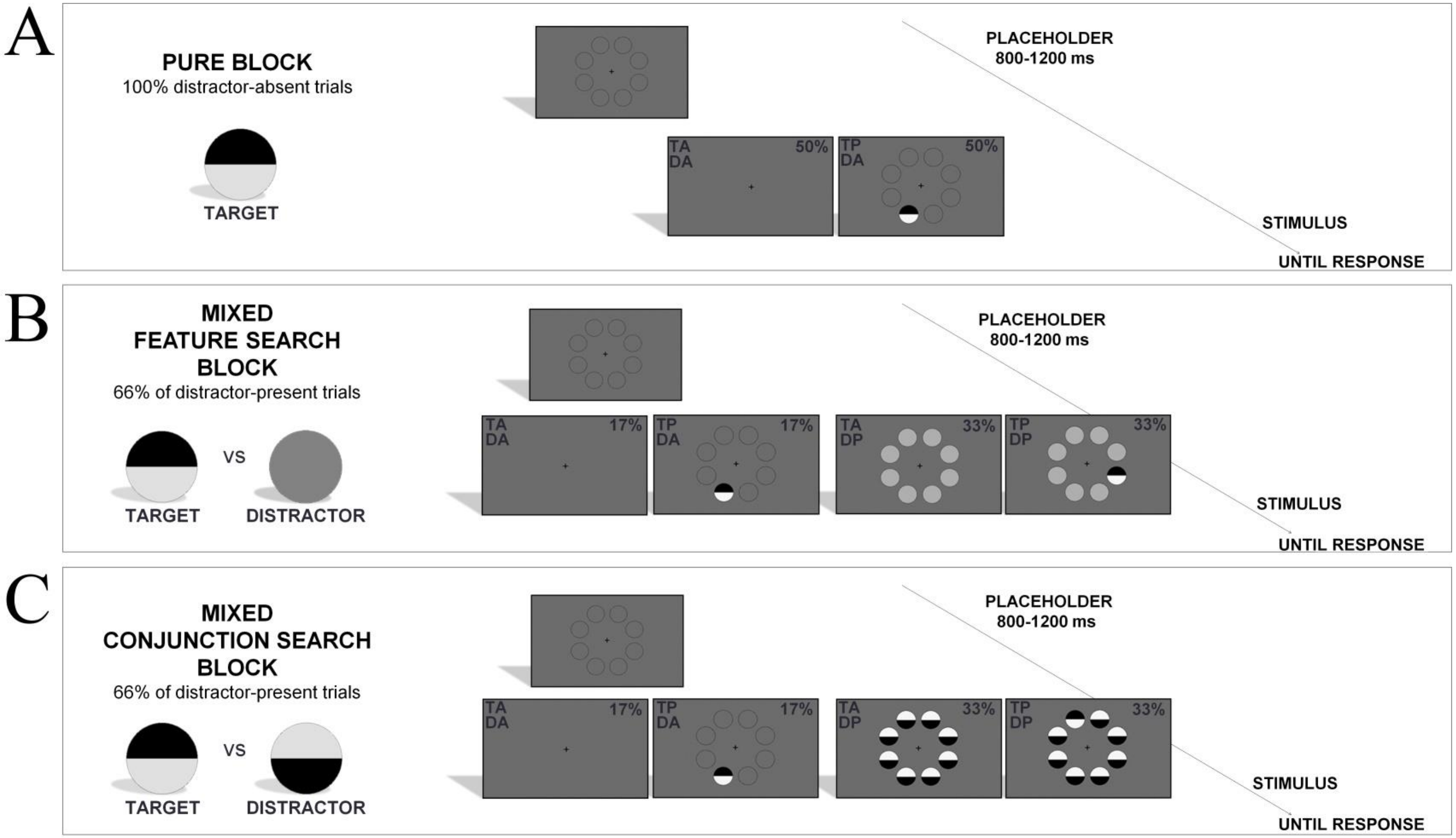

Figure 3.2.1 Schematic representation of the experimental timeline for the three blocks of Experiment 2: Pure search block (Panel A), Mixed Feature search block (Panel B) and Mixed Conjunction search block (Panel C).
Note: TP-DA = Target Present-Distractor-Absent; TA-DA = Target Absent-Distractor Absent; TP-DP = Target Present-Distractor-Present; TA-DP = Target Absent-Distractor Present.

3.2 Methods

3.2.1 Participants

Twenty-four healthy students at the University of Milano-Bicocca volunteered for the experiment in exchange for course credit (4 males, 19-39 years old, mean 23, SD: 4, 21 right-handed). One participant was excluded because of high mean responses latencies in one experimental condition (more than 3 SD relative to the mean response time of the group). All participants had normal or corrected-to-normal vision.

3.2.2 Materials, design and procedure

The equipment, material, design, and procedure were identical to Experiment 1 with the following exceptions: participants were instructed to maintain central fixation before the search array appeared and they were informed that they were free to move their eyes once the search array was displayed. The search array remained visible until a response was made. In this experiment, the onset of stimulus display of TA-DA trials was signaled by the disappearance of the array with empty circles (**Figure 3.2.1**).

3.2.3 Data analysis

The main dependent measures of interest were RTs. Response accuracy was also collected, but, as typically occurs in overt search tasks, it was near ceiling under all conditions (>95%) and therefore is not reported. Data analyses procedures on RTs were identical to those used for Experiment 1.

3.3 Results

3.3.1 Reaction Times

First, a one-way ANOVA was run on TP-DA trials with the 3-level factor Type of Block (Pure, Mixed Feature, Mixed Conjunction) in order to evaluate the presence of a distractor-expectation effect in TP-DA trials of Mixed blocks (as observed in covert search task of Experiment 1). A significant main effect was found (F (2, 44) = 40.552, p < .001) (**Figure 3.3.1 A**).

Post-hoc comparisons revealed a significant slowing-down of performance in both Mixed Feature (t (22) = -4.795, p < .001) and Mixed Conjunction block (t (22) = -8.227, p < .001), indicating that both types of mixed blocks incur on a RT-cost on TP-DA trials caused by distractor-expectation. The difference between the RT-cost of the Mixed blocks was also significant (t (22) = -4.783, p < .001) attesting to slower response in the Mixed Conjunction compared to the Mixed Feature block and, thus, replicating completely the RT-pattern of Experiment 1 (**Figure 3.3.1 B**).

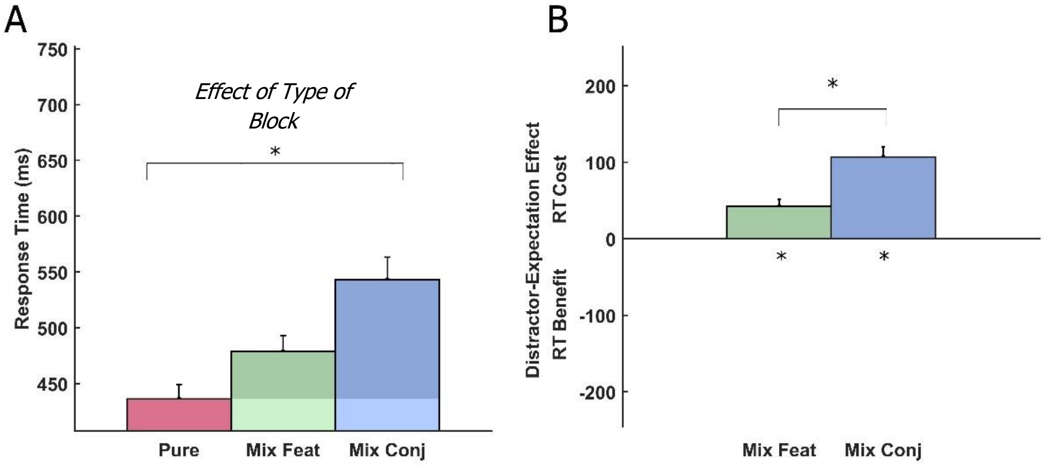

Figure 3.3.1: A) Response Time (RT) results for Experiment 2.

A) The graph shows RTs for Target-Present and Distractor-Absent trials (TP-DA) of the three blocks (i.e., Pure, Mixed Feature, Mixed Conjunction).

B) The graph shows the effect of distractor-expectation on RTs in Target-Present and Distractor-Absent trials (TP-DA) of the Mixed Feature and Mixed Conjunction blocks (i.e., the difference in RTs between TP-DA trials of the Mixed blocks and TP-DA trials of the Pure block).

Asterisks represent the comparison statistically significant (* $p < 0.05$). Error bars represent standard error.

3.3.2 Previous trial modulation

A 2 x 2 ANOVA factoring Type of Block (Mixed Feature and Mixed Conjunction) and Previous Trial Distractors Presence (DA and DP) was conducted to investigate potential trial-to-trial modulations of the RT-cost observed in DA trials of the Mixed blocks (see paragraph 3.3.1). This analysis revealed a main effect of Previous Trial Distractors Presence (F (1, 22) = 15.020, p < .001), with higher RT-cost on DA trials following DP trials compared to DA trials following another DA trial. The main effect of Type of Block was also significant (F (1, 22) = 18.588, p < .001). RT-cost on DA trials of the Mixed Conjunction block were significantly higher than RTs on DA trials of the Mixed Feature block. No significant interaction was observed (F (1, 22) = 1.186, p = .288), indicating that the effect of the presence of distractors in the previous trial did not differ between Mixed Feature and Mixed Conjunction block. Therefore, these results indicate that the RT-cost induced by distractor-expectation in DA trials of Mixed

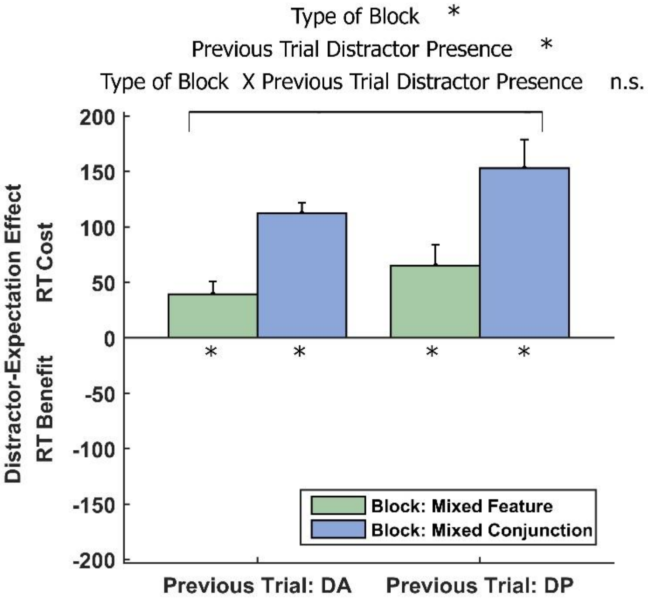

Figure 3.3.2: RT-cost as a function of Type of Block and Previous Trial Distractor Presence for Experiment 2.

The graph shows distractor-expectation RT-costs for Distractor-Absent trials (DA: TP-DA and TA-DA) of the Mixed Feature and Mixed Conjunction blocks (i.e., the difference in RTs between DA trials of the Mixed blocks and the Pure block) separated for DA trials preceded by another DA trial and DA trials preceded by a DP trial (i.e., distractor-present, DP: TP-DP and TA-DP).

Asterisks represent the comparison statistically significant (* p < 0.05). Error bars represent standard error.

blocks was higher in Mixed Conjunction than Mixed Feature block and it was enhanced by the presence of distractors in the previous trials (**Figure 3.3.2**). Finally, in order to evaluate whether the RT-costs were present in all the conditions, we compared the RT-costs of both Mixed blocks against zero with one sample t-tests. These analyses revealed that all the distractor-expectation costs were significantly higher than zero (all $p < .003$) (**Figure 3.3.2)**.

This pattern of results replicates at all that emerged in covert visual search (Experiment 1), indicating that also in overt visual search tasks the distractor-expectation cost depends on mechanisms that are both tonically-activated throughout contexts with expectation for distractors and phasically-reinstated after contingent distractor occurrence.

3.4 Discussion

The pattern of results of Experiment 2 replicated those emerged in Experiment 1. Together, Experiment 1 and 2 revealed that the expectation of distractors recruited proactive processes that entailed a RT-cost in both Mixed Feature and Mixed Conjunction block. Interestingly, the magnitude of the distractor-expectation cost was modulated by the type of search, being larger in the context of conjunction search and smaller in the context of feature search. Moreover, both experiments concurred to suggest the involvement of both a phasic and a tonic component in the recruitment of proactive top-down processes in visual search.

Crucially, the experiments described thus far leave open a relevant question regarding the nature of these proactive top-down processes: is their recruitment dependent on implicit or explicit basis? The existing literature distinguishes between two different modalities of top-down control (for review see Bugg, & Crump, 2012). On the one hand, cognitive control could operate in an explicit fashion in which the implementation of a top-down setting is completely under the volitional and strategical control (e.g., Posner & Snyder, 1975). Such form of “explicit control” has been recently differentiated from a form of “implicit control”, a particular top-down control setting automatically triggered by stimulus context (e.g., King, Korb, & Egner, 2012). The implementation of this implicit contextual control has been described as “on the fly,” that is, it is primed in a rapid online manner by a context-dependent switch from a top-down control state to another. Experiments 1 and 2 showed that proactive top-down processes for distractors expectation were triggered after contingent distractor occurrence in Mixed blocks, suggesting that a form of context-dependent control was implemented. However, these experiments were not designed to distinguish between an explicit or implicit way of functioning. In Experiment 1 and 2, the uncertainty of distractors occurrence in the incoming trials would have made unhelpful the adoption of a strategical control of the proactive top-down mechanisms. Instead, the adoption of an explicit control of proactive top-down processes of distractor expectation might be the optimal strategy if the distraction occurrence was predictable because it would allow to proactively activate top-down processes for dealing with distractors just when distractors are presented in order to not incur in the distractor-expectation cost when distractors are not presented.

Therefore, in Experiment 3 we try to characterize the implicit vs explicit nature of proactive top-down mechanisms involved in visual search by manipulating the predictability of distractor occurrence.

CHAPTER 4

EXPERIMENT 3:

IMPLICIT VS EXPLICIT PROACTIVE TOP-DOWN CONTROL

Chapter adapted from:

Petilli, M.A., Marini, F., & Daini, R., (*in preparation*). Proactive Top-Down Mechanisms in visual search.

4.1 Introduction

Experiment 3 sought to investigate whether proactive top-down mechanisms of distractor expectation are under implicit or explicit control. To this aim, we assessed whether the behavioral signatures of proactive top-down processes in distractor-absent trials are still present when the occurrence of distractors is completely predictable. In order to manipulate the predictability of distraction occurrence, we implemented a Mixed Conjunction block with predictable distractor occurrence and a Mixed Conjunction block with unpredictable distractors occurrence. In the block with predictable distractor occurrence upcoming distractors presence was made foreseeable by alternating DP and DA trials while in the block with unpredictable distractor occurrence DP and DA trials were randomly presented. Since in Experiment 1 and 2 Mixed Feature block and Mixed Conjunction block showed comparable finding in terms of distractor-expectation cost in Experiment 3 we investigated the effect of predictability on the distraction expectation cost only in the Mixed Conjunction block as it showed the stronger effects.

If proactive mechanisms in visual search can be under explicit control one might expect that the response slowing down and the sensitivity improvement observed in distractor-absent trials of previous experiments should disappear when the distractors occurrence is predictable. On the contrary, if this effect persists even in the context of distraction predictability it would indicate that proactive top-down mechanisms are automatically displaced when we are looking for a target in a distracting context.

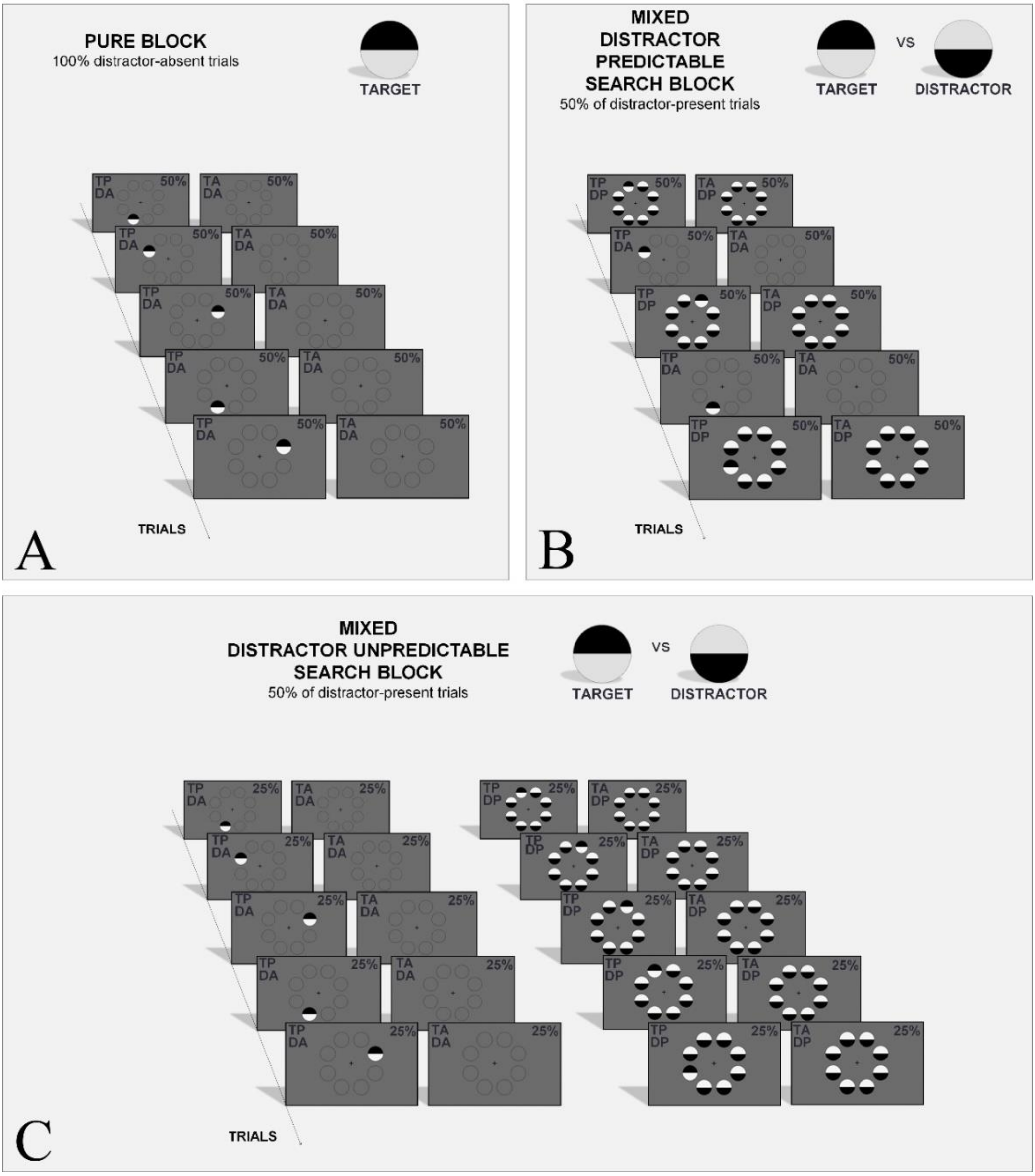

Figure 4.2.1 Schematic representation of the sequence of trials for Experiment 3 for the three blocks: Pure search block (Panel A), Mixed Distractor-Predictable block (Panel B), and Mixed Distractor-Unpredictable block (Panel C). In the Mixed Distractor-Predictable block, upcoming distractor presence was completely predictable by alternating DP (TP-DP and TA-DP) and DA trials (TP-DA and TA-DA). Differently, the sequence of trial of the Mixed Distractor-Unpredictable was random.
Note: TP-DA = Target Present-Distractor-Absent; TP-DP = Target Present-Distractor-Present

4.2 Methods

4.2.1 Participants

Twenty-four healthy students at the University of Milano-Bicocca participated in the experiment (4 males; 18-29 years old, mean 23.2 years, SD: 4.5; 23 right-handed). Participants volunteered to take part in the experiment in exchange for course credit. All participants had normal or corrected-to-normal vision.

4.2.2 Materials, design and procedure

The equipment, material, design, and procedure were similar to Experiment 1 except for the following aspects. No mixed Feature block and two Mixed Conjunction blocks, in addition to the Pure block, were included in the experiment. In one of the two Mixed blocks (Mixed Dist-Predictable), upcoming distractor presence was completely predictable by alternating DP (TP-DP and TA-DP) and DA trials (TP-DA and TA-DA). Differently, in the second Mixed block (Mixed Dist-Unpredictable), trials were randomly presented (**Figure 4.2.1**). As in Experiment 1, each block included 50% TA trials (TA-DA in Pure block; TA-DA and TA-DP in Mixed blocks) and 50% TP trials (TP-DA in Pure blocks; TP-DA and TP-DP in Mixed blocks) but in contrast of Experiment 1 equal numbers of DP and DA trials were included in the Mixed blocks. This change was necessary to allow the systematic alternation of presentation of DP and DA trials in the Mixed Dist-Predictable block. As a result, each Pure block comprised overall 48 trials (24 TP-DA trials; 24 TA-DA trials) while each Mixed block comprised overall 96 trials (24 TP-DA trials; 24 TA-DA trials; 24 TP-DP trials; 24 TA-DP trials). Each block was repeated twice (i.e., resulting in 96 trials for the Pure blocks and 144 trials for the Mixed blocks), and the order of blocks was counterbalanced across participants.

4.2.3 Data analysis

Data analyses were identical to those described for RT in Experiment 1 (see Paragraph 2.3.1) and Experiment 2 (see Paragraph 3.3.1) and for d’ in Experiment 1 (see Paragraph 2.3.2).

In the Mixed Dist-Unpredictable block, DA trials were preceded either by DP trials or by DA trials while in the Mixed Dist-Predictable block DA trials were always preceded by DP trials. Since RTs in DA trials are modulated by the presence of distraction in the previous trial (see paragraph 2.2.3 and 3.3.2), DA trials of the Mixed Dist-Unpredictable block were excluded from the analyses on RTs in order to have comparable trials between the two Mixed blocks.

4.3 Results

4.2.1 Reaction Times

In order to assess whether the RT-cost in TP-DA trials of the Mixed blocks was modulated by distractor predictability, RTs on TP-DA trials were compared with a one-way ANOVA factoring Type of Block (Pure, Mixed Dist-Unpredictable, Mixed Dist-Predictable). A significant effect was found of Type of Block (F (2 ,46) = 40.230, p < .001) (**Figure 4.3.1 B**).

Post-hoc analyses revealed that a significant slowing down was present both in the Mixed Dist-Unpredictable (t (23) = 8.868, p < .001), and Mixed Dist-Predictable (t (23) = 6.783, p < .001) blocks compared to the Pure block. This indicated that distractor-expectation induces a RT-cost both when distractors are unpredictable and when distractors are predictable. No significant difference was found between RT-costs of the Mixed Dist-Predictable vs Mixed Dist-Unpredictable (t (23) = 1.754, p = .278) (**Figure 4.3.1 B**), indicating that the predictability of distractors occurrence does not determine any significant modulation of the distractor expectation cost.

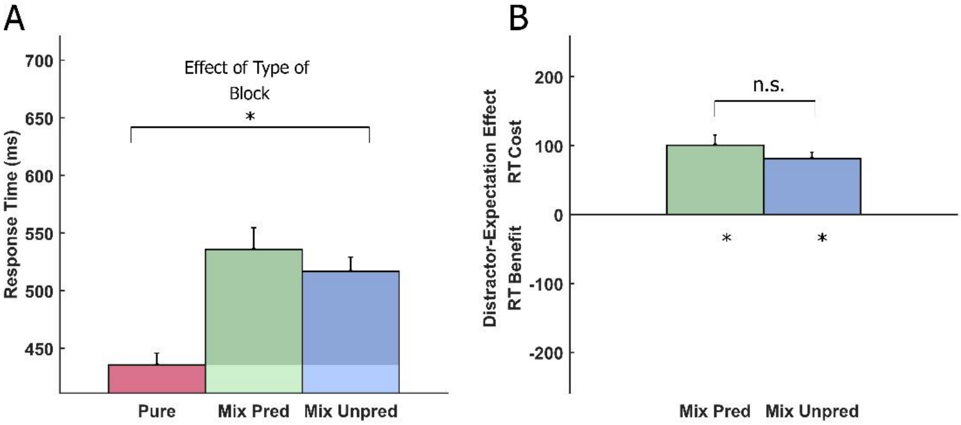

Figure 4.3.1: A) Response Time (RT) results for Experiment 3.

A) The graph shows RTs for Target-Present and Distractor-Absent trials (TP-DA) of the three blocks (i.e., Pure, Mixed Distractor-Predictable, and Mixed Distractor-Unpredictable).

B) The graph shows the effect of distractor-expectation on RTs in Target-Present and Distractor-Absent trials (TP-DA) of the Mixed Distractor-Predictable and Mixed Distractor-Unpredictable blocks (i.e., the difference in RTs between TP-DA trials of the Mixed blocks and TP-DA trials of the Pure block).

Asterisks represent the comparisons statistically significant (* $p < 0.05$). Error bars represent standard error.

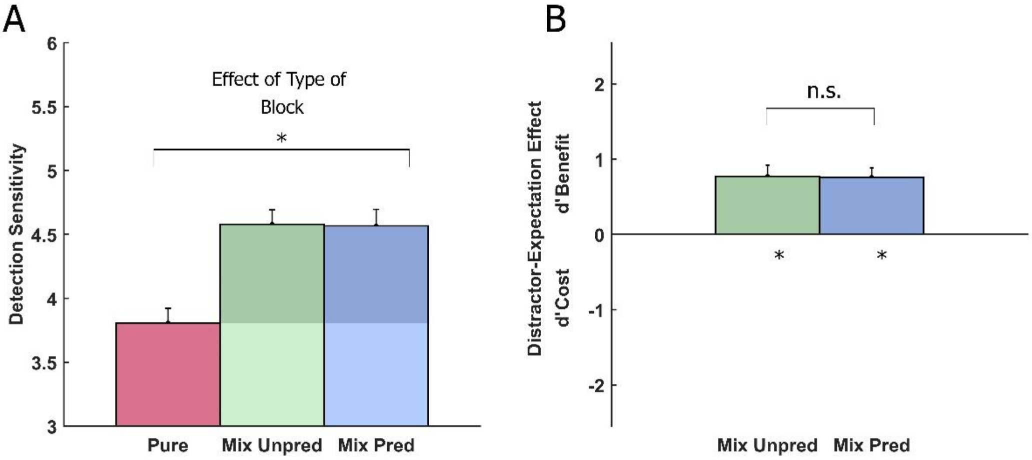

Figure 4.3.2: A) Detection Sensitivity (d’) results for Experiment 3.

A) The graph shows d’ for Distractor-Absent trials (TP-DA and TA-DA) of the three blocks (i.e., Pure, Mixed Distractor-Predictable, and Mixed Distractor-Unpredictable).

B) The graph shows the effect of distractor-expectation on detection sensitivity (d’) in Distractor-Absent trials (TP-DA and TA-DA) of the two Mixed blocks (i.e., Mixed Distractor-Predictable, and Mixed Distractor-Unpredictable).

4.2.2 SDT measures

In order to assess context-dependent changes in detection sensitivity, a Friedman test was conducted with Type of Block as a 3-level factor (Pure, Mixed Dist-Unpredictable, Mixed Dist-Predictable) and showed a significant effect (χ2 (2, 24) = 19.055, p < .001) (**Figure 4.3.2 A**).

One-Sample Wilcoxon Signed Rank tests showed that the difference in d' between both Mixed blocks and the Pure block were significantly higher than zero (all p < .001), indicating that distractor-expectation determines a benefit in DA trials of both types of Mixed blocks. No statistically significant differences emerged when the d'-benefits of the two Mixed blocks were compared (Z = 1.457, p = .435). On the one hand, these results confirmed those of Experiment 1 and indicated an increase in the detection sensitivity on TP-DA trials in Mixed versus Pure blocks. On the other hand, this improvement of detection sensitivity is present not only when distractors occurrence is unpredictable but also when it is predictable (**Figure 4.3.2 B**).

In order to evaluate potential changes in response criterion on DA trials of the three types of blocks an ANOVA factoring Type of Block (Pure, Mixed Dist-Unpredictable, Mixed Dist-Predictable) was conducted. No significant result was found (F (2, 42) = 0.528, p = .594). Finally, to assess the potential occurrence of response biases, response criterion values for each type of block was compared against zero with one sample t-tests and no significant effects were observed (all ps > .431) (see Table 3). Therefore, these results indicated that expectation of distractors did not induce any significant change in response bias.

4.4 Discussion

Experiment 3 investigated whether the activation of proactive top-down control of distractor expectation was modulated by the predictability of distractor occurrence. This allowed to distinguish between the explicit versus implicit recruitment of proactive top-down mechanisms in visual search.

The adoption of an explicit control in the block with predictable occurrence of distractors would have been advantageous since it would have allowed to flexibly implement proactive top-down processes only when needed. Instead, results showed that both the distractor-expectation cost and the d' advantage were found when distraction occurrence was unpredictable (similarly to Experiments 1 and 2) and, crucially, they persisted even when distraction occurrence was made predictable. Thus, top-down control settings for dealing with distractors are likely to be implemented implicitly and as a consequence of the recent experience of a distracting context. However, it is worth noting that these findings have been observed in distractor-absent trials following a distracting experience and, therefore, cannot be generalized to tonic top-down control observed in distractor-absent trials preceded by another distractor-absent trial.

Crucially, previous experiments showing the relevance of the temporal proximity of previous distracting events for the activation of proactive processes raised another important issue: what are the relative contributions of previous experiences and expectations to the recruitment of proactive top-down processes for dealing with distractors? Previous experiments do not give a clear statement. It is possible, for example, that these particular top-down control setting is directly triggered by stimulus context and remain subsequently still active to an extent dependent on the recency of the previous distracting event. Previous experiments cannot help in discriminating between experience-driven and expectancy-driven mechanisms since distractor experience and distractor expectation clearly covary. To disentangle between the relative contributions of previous distracting experience and distractor expectation, in experiment 4, we manipulated the temporal expectation about when the search stimulus occurs. Since temporal expectation of incoming stimulus changed in such a way that it increased inversely to the temporal proximity from the previous stimulus, experiment 4 allowed us to differentiate the relative contribution driven by temporal expectation from those driven by previous distracting experience.

EXPERIMENT 4:
THE CONTRIBUTION OF DISTRACTOR EXPECTATION AND DISTRACTING-EXPERIENCE IN THE RECRUITMENT OF PROACTIVE TOP-DOWN MECHANISMS

Chapter adapted from: Petilli, M.A., Makoto, M., Pion-Tonachini, L., Daini, R., Makeig, S., (*in preparation*). Behavioral and electrophysiological evidences for proactive Top-Down Mechanisms in overt visual search.

5.1 Introduction

Experiment 4 sought to investigate how the recruitment of proactive top-down processes of distractor expectation is modulated over time. To this aim, we tested the effect of distractor expectation when combined with the temporal expectation of occurrence of the search array stimulus on the distractor-expectation costs. In this experiment, the temporal expectation of the search stimulus appearance was manipulated on trial-by-trial basis according to whether the search stimulus was the second (No Temporal Expectation), the third (Likely Temporal Expectation), or the fourth (Certain Temporal Expectation) of a series of four stimuli presented at regular and predictable onsets. Since the temporal expectation of the search stimulus increases as the temporal proximity from the previous stimulus decreases, this paradigm is ideal to differentiate between those behavioral effects modulated by temporal expectation from those driven by previous distracting events. A role of experience was already revealed in previous experiments by showing that the behavioral cost observed in distractor-absent trials of Mixed (vs Pure) blocks is higher in those trials following a distractor-present trial compared to those following a distractor-absent trial. In this experiment we should expect that, if the recruitment of proactive processes for dealing with distractors is totally driven by distracting experience, the magnitude of the behavioral cost observed in distractor-present trials would be modulated by the temporal proximity with the previous trial, in particular when the previous trial is a distractor-present trial. Therefore, this behavioral cost should be higher when the search stimulus is the second compared to when it is the third stimulus of the series. On the contrary, if the recruitment of proactive processes for dealing with distractors is also driven by distractor-expectations, the behavioral costs observed in distractor-absent trials of Mixed (vs Pure) blocks should be modulated according to the time course of temporal expectations about when the search event would occur. Therefore, it should be higher when the search stimulus is the third stimulus (i.e., when the temporal expectation is certain) compared to when it is the second stimulus of the series (i.e., when the temporal expectation is likely).

Differently from previous experiments in which a two-alternative forced-choice method with manual responses was used, in this experiment, we adopted an Oculomotor Capture paradigm (van Zoest, Donk, & Theeuwes, 2004; Heimler et al., 2015), a variant of the overt visual search task. Participants were required to make rapid and accurate saccades from the center of the screen toward the target and ignoring distractors if present at all. Saccades directed toward a distractor were considered erroneous responses. The choice of adopting this paradigm relied on various reasons: first of all, it allowed us to test the consistency of previous findings under other experimental procedures. Second, we took into account that attentional capture is strictly related to eye movements. Therefore, we expected that the adoption of saccadic latencies as dependent variable would be highly reliable in revealing the outcome of visual selection performance. Third, the Oculomotor Capture paradigm has been already demonstrated to be ideal in studying the interplay of stimulus-driven attentional capture and top-down control in visual search (van Zoest et al, 2004; Heimler et al., 2015). Finally, this paradigm had the advantage of making heavily ineffective the adoption of a guessing strategy: random guess had a 12.5% chance of being correct (i.e., one correct response out of eight possible responses in distractor-present trials) compared to a 50% chance of correct guessing in a two-alternative forced-choice task.

5.2 Methods

5.2.1 Participants

Twenty-four healthy students at the University of California, San Diego participated in the experiment (15 males, 18-38 years old, mean 24.5 years, SD: 5.65, 24 right-handed). All participants had normal vision. Participants volunteered to take part in the experiment. Each participant received 15 dollars/hour for his or her participation.

5.2.2 Equipment

For the entire duration of the experiment, participants sat in a darkened room with their eyes at 57 cm from the center of a 17’’ LCD color monitor (Dell E176FPf, resolution 1080 x 1024 pixels, 75Hz) controlled by means of a chinrest.

In order to record eye movements an EyeLink tracker (EyeLink 1000 Desktop Remote, SR Research) with 0.05 spatial resolution and 1000 Hz, temporal resolution was used. The experimental routine was written with the Psychophysics Toolbox 3 (Pelli, 1997; Kleiner, et al., 2007) for Matlab R 2013a (Mathworks Inc.).

5.2.3 Materials, procedure, and experimental design

The search array stimuli were identical to Experiment 1, 2 and 3 with the exception that only TP (TP-DA and TP-DP) trials were included in this experiment.

At first, participants were informed that they were about to execute three different blocks of visual search tasks. They were informed about which stimulus was the target, and which stimuli were distractors. Participants were instructed to maintain fixation until the search display appeared and then to move their eyes as fast and accurate as possible to the target, ignoring, if present, the distractors. They were also told that the target could appear alone or among distractors depending on the type of visual search block. All participants received written instructions. Before the beginning of each block, participants were cued about the type of the upcoming block (I.e., Pure, Mixed Feature, or Mixed Conjunction block). Participants completed each block thrice (the order was counterbalanced across participants).

Trials started when participants started fixating the central cross. If participants looked away from the central fixation cross before the search display appeared, a warning message was displayed reminding subject to keep eyes centered before search display appeared. Thus, the trial restarted from the beginning once subject looked again at the central fixation cross. Each block comprised 120 trials each (i.e., resulting in 360 trials for each block). Before the beginning of the experiment, participants received 32 practice trials for each block.

Figure 5.2.1 illustrates a schematic representation of the timeline and of the structure of the experiment.

Manipulation of distractor expectation

Distractor expectation was modulated at a block level: the structure of the blocks (i.e., Pure block, Mixed Feature block, or Mixed Conjunction block) were identical to Experiment 1, 2 and 3.

Manipulation of temporal expectation of search stimulus presentation

In each trial, a variable number (2 or 3) of placeholder array stimuli lasting 50 ms were presented repetitively at regular 800 ms intervals before search array stimulus presentation. The interval between successive stimuli (i.e., the placeholder stimuli and the search stimulus) was kept fixed to facilitate the temporal prediction of the appearance of the stimuli. The temporal expectation of the search appearance was manipulated on a trial-by-trial basis according to whether the search stimulus was the third or the fourth stimulus presented within the trial. In ~67% of the trials of each block, the search stimulus was preceded by 2 placeholder stimuli. Thus, the interval between the beginning of the trial and the search display was of 1600 ms (i.e., the placeholder stimuli were presented at 0 ms and 800 ms while the search stimulus appeared at 1600ms). In the remaining 33% of trials, the search stimulus was preceded by 3 placeholder stimuli. Thus, the interval between the beginning of the trial and the search stimulus was of 2400 ms (i.e., the placeholder stimuli were presented at 0 ms, 800 ms, and 1600 ms while the search stimulus appeared at 2400 ms). This temporal structure allowed us to modulate the temporal expectation of the presentation of the search stimulus in three time-interval (50-800 ms, 850-1600ms, and 1650-2400ms). Specifically, none expectation for impending presentation of the search stimulus was induced in the time range preceding the second stimulus (i.e., 50-800 ms) (i.e., the second stimulus was the search array with 0% likelihood). Likely expectation for impending presentation of the search stimulus was induced in the time range preceding the third stimulus (i.e., 850-1600 ms) (i.e., the third stimulus was the search array with ~67% likelihood). Finally, certain expectation for impending presentation of the search stimulus was induced in the time range preceding the fourth stimulus (i.e., 1650-2400 ms) in the remaining trials (i.e., in these trials, the fourth stimulus was the search array with 100% likelihood). Therefore, ‘No Temporal Expectation’ will be used in this paper to refer to time widows preceding events, or to responses following events that occur at 800 ms (i.e., the onset of the second stimulus in the series), that is when no expectation of search stimulus occurrence is induced in the subject. ‘Likely Temporal Expectation’ will be used in this paper to refer to time widows preceding events, or to responses following events that occur at 1600 ms (i.e., the onset of the third stimulus in the series), that is when a likely expectation of search stimulus occurrence is induced in the subject. Finally, ‘Certain Temporal Expectation’ will be used in this context to refer to time windows preceding events, or to responses following events that occur at 2400 ms (i.e., the onset of the fourth stimulus in the series), that is when certain expectation of search stimulus occurrence is induced in the subject.

The sequence of the trials within each block was randomized.

5.2.4 Data analysis

Behavioral analyses were focused on the effects of distractor expectation when combined with temporal expectation and type of preceding trial on saccadic latencies (i.e., the difference between saccadic latencies of the Mixed blocks and the Pure block). Eye movements were considered as directed to the target item or to a distractor item when the saccade fell within a radius of 2.5 degrees of visual angle around the center of the item. This area of tolerance allowed for the inclusion of saccadic undershoots and saccadic overshoots (Kapoula & Robinson, 1986). Trials were included in the analyses only if the saccadic movement were directed to the target. Trials with saccadic latencies faster than 80 ms (anticipatory responses) or exceeding the third quartile plus 1.5 interquartile ranges (delayed responses) were eliminated (Ratcliff, 1993).

Statistical analyses were performed on saccadic latencies and distractor-expectation costs, defined as the slowing-down of saccades in DA trials of the Mixed blocks vs DA trials of the Pure block. To investigate phasic and tonic modulations of the distractor expectation cost separately, saccadic latencies of DA trials of the Mixed blocks were sorted according to the type of preceding trial (DP or DA). Statistical comparisons were conducted with one-sample t-test, paired-sample t-tests and repeated-measure analyses of variance (ANOVA). When significant main effects and/or interactions emerged, they were further explored with pairwise comparisons using a false discovery rate (FDR) correction for multiple comparisons (Benjamini & Hochberg, 1995).

5.3 Results

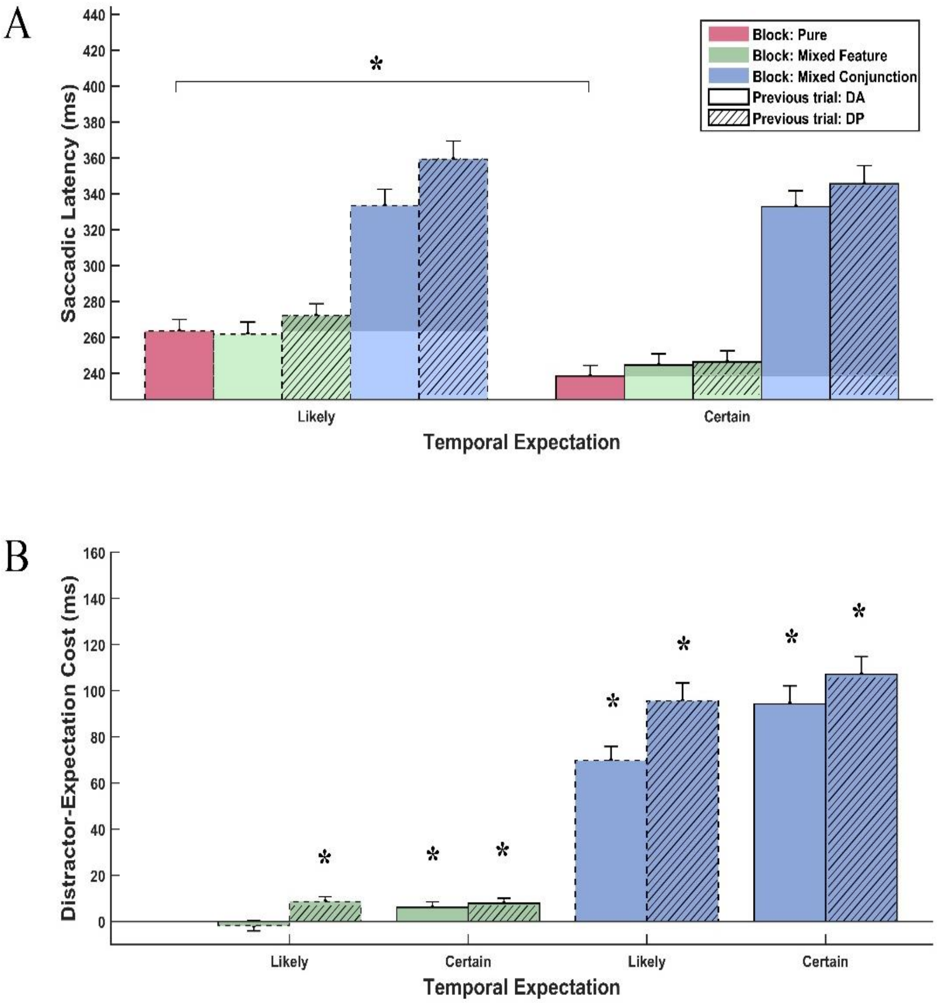

Figure 5.3.1: A) Saccadic latency results for Experiment 4.

A) The graph shows saccadic latencies for Target-Present and Distractor-Absent trials (TP-DA) of the three blocks (i.e., Pure, Mixed Feature, Mixed Conjunction) separately for Temporal Expectation (Likely vs Certain) and Previous Trial Distractor Presence (Previous Trial: Distractor Absent VS Previous Trial: Distractor Present). Note: only the comparison between saccadic latencies of DA trials of the Pure block are statistically evaluated here.

B) The graph shows the effect of distractor-expectation on saccadic latencies in Target-Present and Distractor-Absent trials (TP-DA) of the Mixed Feature and Mixed Conjunction blocks (i.e., the difference in saccadic latency between DA trials of the Mixed blocks and DA trials of the Pure block) separately for Temporal Expectation (Likely vs Certain) and Previous Trial Distractor Presence (Previous Trial: Distractor Absent VS Previous Trial: Distractor Present).

Asterisks represent the statistically significant distractor-expectation costs when compared against zero (* $p < 0.05$). Error bars represent standard error.

First, we tested whether and how temporal expectation modulates saccadic latencies in absence of any potential effect induced by the interaction of temporal and distractor expectation. Thus, we compared saccadic latencies of DA trials of the Pure block in the condition of Certain VS Likely Temporal Expectation with a paired-sample t-test. As expected, this analysis revealed a significant decrease of saccadic latencies in the condition of Certain (VS Likely) Temporal Expectation (t (23) = 7.75; p < .001) indicating that saccadic latency benefits from certainty about when the target event occur (**Figure 5.3.1 A**).

The potential occurrence of a saccadic latency-cost caused by distractor-

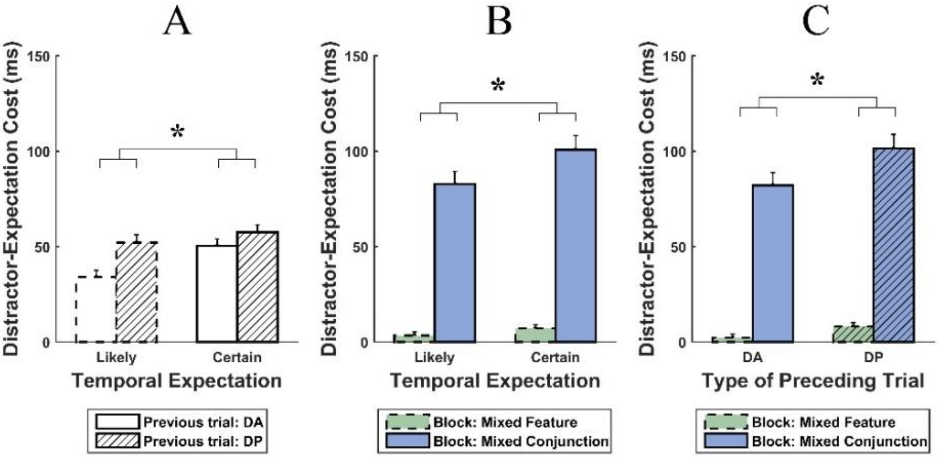

Figure 5.3.2: Interaction effects between Type of Block and Temporal Expectation (A), Type of Block and Type of Preceding Trial (B), and Type of Preceding Trial and Temporal Expectation (C) for experiment 4.

A) The graph shows the saccadic latency-cost induced by distractor-expectation as a function of the interaction between Type of Block (i.e, Mixed Feature vs Mixed Conjunction block) and Temporal Expectation (i.e., Likely vs Certain).

B) The graph shows the saccadic latency-cost induced by distractor-expectation as a function of the interaction between Type of Block (i.e, Mixed Feature vs Mixed Conjunction block) and Type of Preceding Trial (i.e., Distractor-Absent vs Distractor-Present).

C) The graph shows the saccadic latency-cost induced by distractor-expectation as a function of the interaction between Type of Preceding Trial (i.e., Distractor-Absent vs Distractor-Present) and Temporal Expectation (i.e., Likely vs Certain).

Asterisk indicate that the effect of interaction is significant (* p < 0.05). Error bars represent standard error.

expectation in all DA trials condition (i.e., Type of Block X Type of Preceding trial x Temporal Expectation) was evaluated by comparing the distractor-expectation costs of DA trials of all the conditions (i.e., the difference in saccadic latency between DA trials of the Mixed blocks and the Pure block) against zero with one sample t-tests. This analysis revealed that distractor expectation induced significant saccadic latency-costs in all the condition (all $p < .02$), except for the saccadic latency-cost of DA trials preceded by another DA trial in the condition of likely temporal expectation of the Mixed Feature block (**Figure 5.3.1 B)**.

Then we analyzed whether and how the distractor-expectation cost (i.e., the slowing down of saccadic latency induced by distractor expectation in DA trials of Mixed blocks) change as a function of the Type of Block, the Type of Preceding trial, and Temporal Expectation. Thus, distractor-expectation costs were submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Mixed Feature vs Mixed Conjunction), Type of Preceding Trial (DP or DA), and Temporal Expectation (Likely vs Certain). The main effects of Type of Block ($F (1, 23) = 142.44$, $p < .001$), Type of Preceding Trial ($F (1, 23) = 32.66$, $p < .001$), and Temporal Expectation ($F (1, 23) = 33.24$, $p = .001$) were significant. However, these main effects were qualified by significant interactions between Type of Block and Temporal Expectation ($F (1, 23) = 13.38$, $p = .001$), Type of Block and Type of Preceding Trial ($F (1, 23) = 30.47$, $p < .001$), and Type of Preceding Trial and Temporal Expectation ($F (1, 23) = 12.13$, $p = .002$). On the contrary, no significant interaction between Type of Block, Type of Preceding Trial, and Temporal Expectation was observed ($F (1, 23) = .47$, $p < .499$).

We, therefore, evaluated how the effect of temporal expectation on the distractor expectation costs was modulated by the type of preceding trials (**Figure 5.3.2 A**). Post-hoc comparisons indicated that, the distractor-expectation costs were significantly higher in DA trials following a DP trial (vs DA trials following another DA trial) both when temporal expectation was Likely (t (23) = 6.96, p < .001) and when temporal expectation was Certain (t (23) = 2.57, p = .017). This indicates that the distractor-expectation cost is modulated by the type of preceding trial, being higher in DA trials presented after a distracting context, confirming a role of temporal proximity with previous distracting context in the modulation of this cost (see Experiment 1, 2, and 3). However, post-hoc comparisons indicated also that in DA trials, either following a DP (t (23) = 2.26, p = .034) or a DA trial (t (23) = 6.54, p < .001), the distractor-expectation costs were significantly higher in case of Certain temporal expectation compared to when it was Likely. This indicated that the distractor-expectation cost is also modulated by temporal expectation, being larger when the temporal expectation about when the search event would occur is Certain (VS Likely). On the other hand, this result showed that, not only for DA trials following another DA trial but also for DA trials following a DP trial, the distractor-expectation cost increases as the temporal proximity with recent distracting context deceases. This suggests that temporal expectations play a greater role in the modulation of the distractor-expectation costs compared to temporal proximity with previous distracting context.

Then, we evaluated how temporal expectation differentially modulates the distractor-expectation cost in Mixed Feature and Mixed Conjunction blocks (**Figure 5.3.2 B**). Post-hoc comparisons indicated that the distractor-expectation costs were significantly higher in those DA trials of the Conjunction block compared to those of the Feature block both when temporal expectation was Likely (t (23) = 11.58, p < .001) and when temporal expectation was Certain (t (23) = 11.53, p <. 001). This indicates that the distractor-expectation cost is modulated by task demands regardless of the level of temporal expectation, being always higher in DA trials of Mixed Conjunction compared Mixed Feature block.

Moreover, post-hoc comparison also showed that the increase of the distractor-expectation cost induced by higher temporal expectation was significant only in the Mixed Conjunction block (t (23) = 5.57, p < .001), while it showed only a trend toward the level of significance in the Mixed Feature block (t (23) = 1.73, p = .095). This indicates that the magnifying effect induced by higher temporal expectation on the distractor-expectation cost is modulated by task demands, being larger when distractors are expected in the context of Conjunction Search compared to Feature Search.

Finally, we tested how the type of the preceding trial modulates the distractor-expectation cost in Mixed Feature and Mixed Conjunction blocks (**Figure 5.3.2 C**). Post-hoc comparisons indicated that the distractor-expectation cost was significantly higher in the Conjunction block compared to the Feature block when DA trials were preceded by either a DA trial (t (23) = 11.27, p < .001) or a DP trial (t (23) = 12.26, p < .001). Again, these results indicate that both in DA trials preceded by a DP trial and DA trials preceded by a DA trial, the distractor-expectation cost is modulated by task demands, being always higher in DA trials of Mixed Conjunction compared to Mixed Feature block. On the other hand, significant increases in the distractor-expectation cost in DA trials preceded by a DP trial compared to those DA trials preceded by a DA trial were observed in both Mixed Feature (t (23) = 3.56, p=.002) and Mixed Conjunction block (t (23) = 6,16 p < .001). The interaction effect indicates that this increase of the distractor-expectation cost is stronger in the Mixed Conjunction block compared to the Mixed Feature block.

5.4 Discussion

Experiment 4 investigated how the recruitment of proactive top-down processes is modulated over time by distractor-expectation and by proximity from previous a distracting experience. Besides the manipulation of the type of expected distractor (i.e., high contrast distractors in Mixed Conjunction and low contrast distractors in Mixed Feature block), here top-down expectations of the distracting event were manipulated also at a temporal level by changing the level of temporal certainty of occurrence of the search stimulus. Since the level of temporal certainty of search stimulus occurrence increased inversely to the temporal proximity from the previous stimulus, this manipulation allowed us also to compare the separated effect of temporal expectation and temporal proximity on the distractor-expectation cost. Moreover, the recency of previous distracting experience was also operationalized, as in the previous experiment, according to whether or not a distracting experience occurred in the immediately preceding trial.

Results of this experiment attested for a combined effect of expectation and experience in the activation and modulation of proactive top-down control when dealing with distractors. As in previous experiments, also this experiment indicates that proactive top-down processes are triggered by contingent distractor occurrence in Mixed blocks, suggesting that a form of experience-driven control is implemented. At the same time, the activation of proactive top-down processes is also strongly modulated by top-down expectation about the type of search task and the when the search event would occur. In fact, consistently with previous studies, also this experiment demonstrates that the activation of proactive top-down processes is strongly modulated by the type of expected task demands, being enhanced in the context of conjunction search compared to the context of feature search. At the same time, this experiment shows that the activation of proactive top-down processes follows also the time course of temporal expectation, being boosted as the temporal certainty of occurrence of the distracting event increases.

Although feature and conjunction search show similar effect driven by distractor-expectation and distractor-experience, it is worth noting that their time courses of activation of proactive top-down processes are not totally overlapping. The activation of proactive top-down processes in feature search has been observed only after a recent distracting experience and/or when the distracting event is temporally expected with certainty. No observable activation of proactive top-down processes is shown when neither of these two conditions is met, suggesting that proactive top-down processes in feature search are dynamically invoked on strategic basis. Instead, in conjunction search, proactive top-down processes of distractor expectation seem to remain activated even when the distracting event are not temporally expected with certainty and the search event occurs after a not distracting experience. When one of these two conditions is met, the level of activation of proactive top-down processes results to be enhanced, reaching the maximum level of activation when both the two conditions are met. These findings suggest that in conjunction search the activation of proactive top-down processes is sustained throughout the potentially distracting session although the level of their activation is dynamically modulated on expectation and experience basis.

Crucially, the experiments described thus far cannot provide substantial evidence for arguing the attentive nature of such proactive top-down mechanisms. Experiment 1 demonstrated that distractor expectation determines both a RT-cost and a d’-benefit when distractors are expected but not presented. Although the effect of distractor expectation on RT has been reported in various studies (Marini et al., 2013, 2015, 2016) and has been linked to the recruitment of proactive top-down processes for distraction filtering, the effect of distractor-expectation on the detection sensitivity has never been described before. The modulation of the sensitivity to detect the target observed when distractors are expected but not presented seems to suggest the engagement of a preparatory attentional state for sensory processing facilitation of relevant stimuli (biased competition theory Desimone & Duncan 1995; Couperus & Mangun, 2010; Mangun and Hillyard, 1987; Serences, & Boynton, 2007) when expected in a distracting context. If that is the case, the engagement of preparatory attentional mechanisms of distractor expectation would be manifested in the modulation of the activity in brain areas for sensory processing (Serences, & Boynton, 2007, Noonan, Crittenden, Jensen, & Stokes, 2017). In order to provide electrophysiological evidence for the involvement of attentional processes of distractor expectation both in Feature and Conjunction search, in chapter 6, we investigated whether and how during visual search distractor expectations combined to temporal expectation modulate early occipital activity.

CHAPTER 6

EXPERIMENT 4:

EEG CORRELATES OF DISTRACTOR EXPECTATION IN LOWER SENSORY AREAS

Chapter adapted from: Petilli, M.A., Makoto, M., Pion-Tonachini, L., Daini, R., Makeig, S., (*in preparation*). Behavioral and electrophysiological evidence for proactive Top-Down Mechanisms in overt visual search.

6.1 Introduction

Electrophysiological data reported in chapter 6 were collected during the experiment discussed in the previous chapter. In this chapter, we sought to investigate whether and how during visual search the recruitment of proactive top-down processes of distractor expectation modulate pre-stimulus and post-stimulus occipital electrophysiological activity. Selective attention research has revealed that predictions about the locations or other features of relevant events can bias occipital neural activity starting from early stages of perceptual analysis (Luck, Chelazzi, Hillyard, & Desimone 1997; Posner & Gilbert, 1999; Gandhi, Heeger, & Boynton, 1999). Response enhancement at these stages is considered the signature for attention at the neural level. Other relevant attention-related modulation of electrophysiological activity has been shown at brain oscillation level. In particular, several studies have shown that anticipatory attention modulates oscillatory brain activity, particularly in the alpha band, implicated in regulating occipital excitability (Foxe, Simpson, & Ahlfors, 1998; Kelly, Lalor, Reilly, & Foxe, 2006; Thut, Nietzel, Brandt, & Pascual-Leone, 2006; O'Connell, Dockree, Robertson, Bellgrove, Foxe, & Kelly, 2009; Van Dijk, Schoffelen, Oostenveld, Jensen, 2008). These alpha modulations are linked to two main attentional processes: on the one hand, alpha desynchronization has been linked to improved target detection and visual processing (e.g., Van Dijk, et al., 2008).

On the other hand, alpha synchronization has been demonstrated to reflect an active retinotopic mechanism for distractor suppression during sustained visuospatial attention (e.g., Kelly et al, 2006). In the context of this study, we sought to investigate whether these electrophysiological signatures for attention are modulated by distractor expectation when combined with temporal expectation. Evidence of attentional modulations induced by distractor expectation on sensory visual areas would be revealed in those electrophysiological activities which will prove to be modulated by distractor expectation following the time course of temporal expectation of the target stimulus.

Therefore we, first, investigated whether different type and degree of distractor expectancy are associated to attentional modulations of early sensory-specific visual ERP components locked to the search stimulus. To this aim, we analyzed whether distractor expectation combined to the temporal expectation of the search stimulus modulated the P1 and N1 components (Luck & Hilliard, 1994) elicited in physically identical distractor-absent trials of the three blocks. Better preparatory attention would be reflected by larger sensory P1 and N1 waves (Doherty, Rao, Mesulam, & Nobre, 2005; Van Den Berg, Clark, Lorist, & Woldorff, 2016). However, if any potential modulation would be revealed, it would be evoked by the combination of distractor-expectation and the presentation of the target stimulus. But if any potential modulation is purely induced by proactive preparation for distractors we should expect a similar modulation even when the visual stimulus change, but the distractor expectations remain the same. Therefore, ERP analyses were also focused on the distractor-expectation modulation of the early P1 and N1 components elicited by non-target stimuli (i.e., when placeholder stimuli were presented) to reveal those electrophysiological modulations purely related to distractor-expectation.

Finally, we investigated whether distractor expectation modulated pre-stimulus brain activity in the alpha band, known to be implicated in regulating excitability in visual areas as a function of anticipatory attention (Rohenkohl & Nobre, 2011; Mazaheri, Di Quattro, Bengson, & Geng, 2011; Romei, Brodbeck, Michel, Amedi, Pascual-Leone, & Thut, 2007). As observed in previous studies, better preparatory attention would be reflected by less pre-stimulus alpha-band oscillatory activity (Van Den Berg et al, 2016).

6.2 Methods

6.2.1 Participants, Materials, design and procedure

Participants, Materials, design, and procedure are described in the previous chapter (see **Paragraph 5.2**). One participant was excluded from EEG analyses because of technical problem of EEG recording.

6.2.3 EEG recording

EEG data were collected with a 128 channel (plus two mastoid electrodes), custom, coverage electrode cap using an amplifier (Biosemi Active II) at a sampling rate of 512 Hz with 24-bit A/D resolution. The montage included twelve midline sites (C2, C6, C11, C16, C21, C26, D01, D03, D07, D12, D17, and D23) and 58 sites over each hemisphere (Right: B1-B32, C1, C5, C10, C15, C20 C25, C30, D6, D11, D16, and D22; Left: A1-A32, C3, C7, C12, C27, C31, C17, C22, D8, D13, D18, and D24). During cap application, offset of all channels was adjusted to below 25 mV. Simultaneously to the EEG recording, events onset and offset of the task and eye position was recorded. Lab Streaming Layer (https://github.com/sccn/labstreaminglayeer, Delorme et al., 2011) acquisition system was adopted for the collection and synchronization of the multiple data streams.

6.2.2 EEG data analysis

General preprocessing

Preprocessing of EEG data were executed using custom MATLAB R2013a (The Mathworks, Inc.) scripts operating in the EEGLAB environment (Delorme and Makeig, 2004). Data were downsampled at 250 Hz. A high-pass finite impulse response (FIR) filter at 1 Hz (cut-off frequency, 0.5 Hz) was applied. The electrical power line noise at 60 Hz was removed using the CleanLine plug-in (Mullen, 2012).

Bad channels were rejected using the *clean_rawdata* plugin of EEGLAB. Non-stationary high variance signals were corrected from continuous data (>5 standard deviation) using Artifact Subspace Reconstruction (Mullen et al., 2015). Data of rejected channels were reconstructed by interpolating from neighboring electrodes using the EEGLAB spherical interpolation function. Data were re-referenced to average reference. Continuous data were decomposed into source-resolved activities using Independent Component Analysis (AMICA) (Palmer et al., 2008) for each participant’s datasets. Artefactual independent components (eye movements, blinks, muscle, heart and line noise) were determined by visual inspection (Pion-Tonachini, http://reaching.ucsd.edu:8000/tutorial/labels). The contributions of artefactual sources were eliminated from continuous data. The channel data were low-pass filtered (40 Hz).

Data analysis

Statistical analyses were performed using custom MATLAB R2013a (The Mathworks, Inc.) scripts operating in the EEGLAB (Delorme and Makeig, 2004).

Group-level analyses were performed on both event-related potential (ERP) and event-related spectral perturbation (ERSP) data. For the ERP analyses continuous data of each block were segmented into epochs from 1 s before to 2 s after: (1) the onset of TP-DA search stimuli presented after two placeholder stimuli, (2) the onset of the TP-DA search stimuli presented after three placeholder stimuli, (3) the onset of the second placeholder stimuli in those trials with three placeholder preceding the search stimulus, (4) the onset of the third placeholder stimuli in those trials with three placeholder preceding the search stimulus. All ERP epochs were corrected using a baseline time window between 50 and 0 ms preceding the onset of the stimulus.

For the ERSP analyses, continuous data of each block were segmented into epochs from 3 s before to 1 s after the onset of the search stimuli presented after three placeholder stimuli. All ERSP epochs were corrected using a baseline time window between the onset of the first placeholder (i.e., -2400) and the onset of the second placeholder (1600 ms) (i.e. the time window when no expectation for incoming search stimulus was induced in the participants).

In order to compare conditions with the same number of trials, by means of a random selection of trials each condition was matched to the condition with the fewest number of trials. Statistical analyses were conducted performing repeated-measure analyses of variance (ANOVA) containing the following factors: Type of Block (Pure vs Mixed Conjunction block vs Mixed Feature block) and Temporal Expectation (None vs Likely or Likely vs Certain). When significant ANOVA effects and/or interactions emerged, they were further explored with one-sample t-test or paired-sample t-tests using a false discovery rate (FDR) correction for multiple comparisons (Benjamini & Hochberg, 1995). The effects resulting from the ANOVAs were not tested separately for trials preceded by a distractor-present and trial preceded by a distractor-absent trial because there were not sufficient trials for accurately estimating ERP and ERSP activity.

ERP analyses

For our analyses, a hypothesis-driven approach was used. Since we were interested in evaluating whether distractor and temporal expectation modulate early occipital ERP activity related to visual search processing, we restricted our analysis to the posterior electrodes (channels D25, D31, D18, and D24, corresponding to the sites in our caps nearest to standard sites P07 and O1, and channels D21, D28, D16, and D22 corresponding to our sites nearest to standard sites P08 and O2) and to time windows classically associated to P1 (i.e., ~75-150) and N1 (i.e., ~150-250) components of visual search tasks (Luck & Hillyard, 1994). Statistical analyses of ERPs were focused on mean amplitudes and peak latencies of the grand-averaged waveform. The time windows adopted for this study were defined after visual inspection of the grand average ERPs components elicited within the expected time windows for the P1 and N1 elicited in DA trials across all the blocks. Positive and negative peaks were then identified for each condition and for each subject respectively as the local maximum and the local minimum of the grand-averaged waveform within the specific time windows of interest. Mean

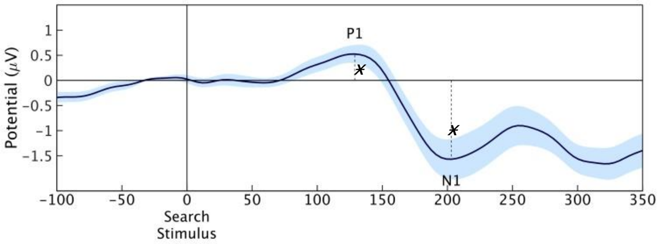

Figure 6.3.1: Search stimulus locked ERP over occipital electrodes averaged across all DA trials of all the blocks.

amplitudes were determined for each participant by measuring the mean amplitude within the 51-ms time window surrounding each peak (25 ms before and after).

ERSP analyses

In order to evaluate whether distractor and temporal expectation modulate anticipatory spatial attention, our ERSP analyses were restricted on alpha power (8-12 Hz) perturbation recorded on the posterior electrodes (i.e., the same electrodes selected for ERP) in the 400 ms preceding the onset of the third placeholder stimulus and the onset of the search stimulus.

6.3 Results

6.3.1 ERP locked to search stimulus onset

Figure 6.3.1 shows the ERP activity locked to the search stimulus onset over occipital electrodes averaged across all DA trials of all the blocks. This ERP activity showed a significant positive deflection (t (22) = 4.98, p < .001) within the time window ~80-160 ms (mean peak latency: 121 ± 18 ms; mean amplitude 0.73 ± 0.7 μV). Moreover, this activity showed also a significant negative deflection (N1) in response to DA trials (t (22) = 6.13, p < .001) within the time window ~160-240 ms (mean peak latency: 204 ± 23 ms; mean amplitude -2.08 ± 1.63 μV).

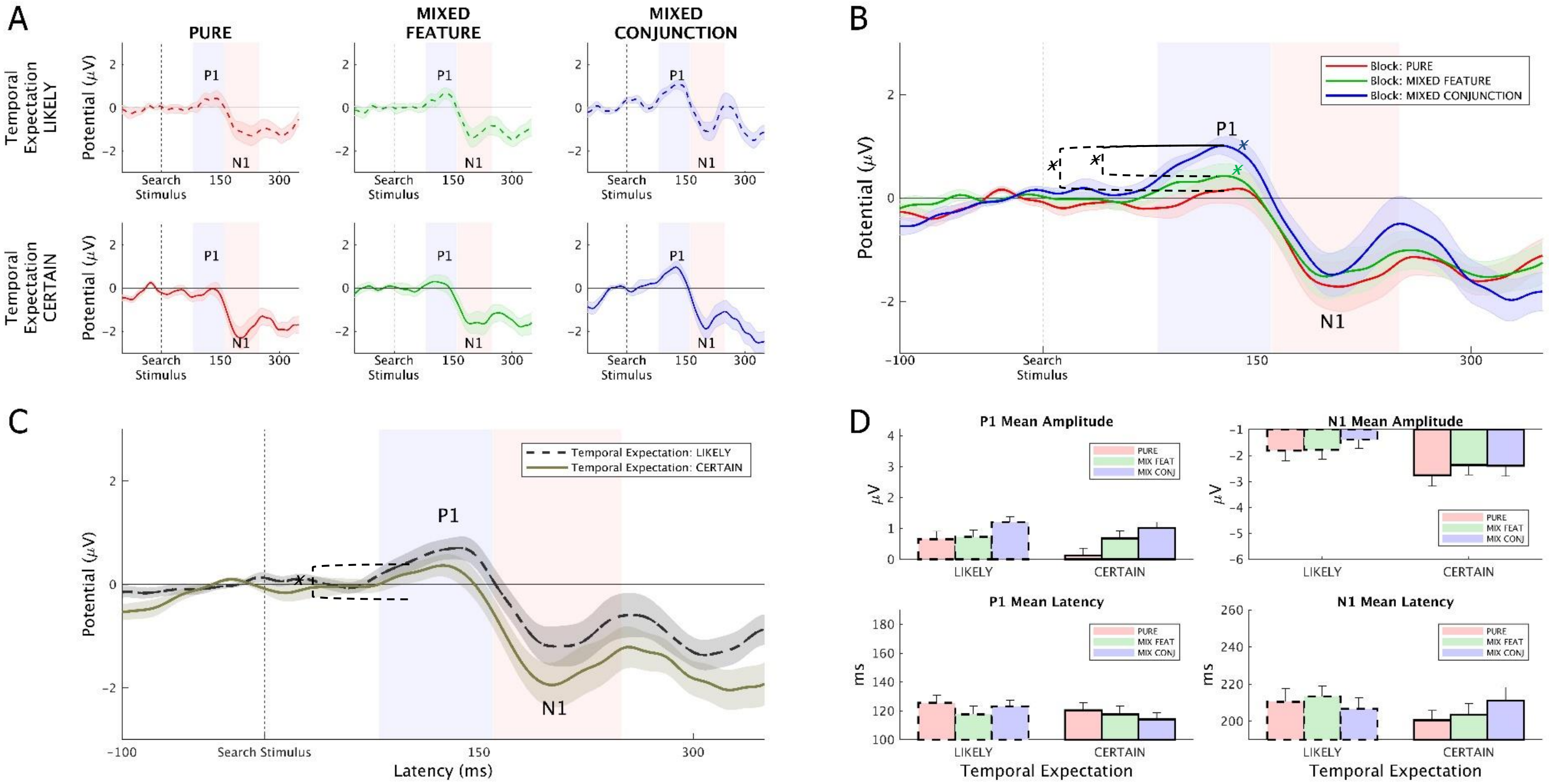

Figure 6.3.2: Early search stimulus locked ERP activity over occipital electrodes for DA trials of Pure, Mixed Feature and Mixed Block in both Likely and Certain temporal expectation of stimulus presentation.

A) P1 and N1 components elicited in DA trials of Pure, Mixed Feature and Mixed Block in Likely and Certain temporal expectation of stimulus presentation. Shaded areas depict standard error B) P1 and N1 components in DA trials of Pure, Mixed Feature and Mixed Conjunction Block. Shaded areas depict standard error C) P1 and N1 components in DA trials of the conditions of Likely Temporal Expectation and Certain Temporal Expectation. Shaded areas depict standard error D) The graphs show mean amplitudes and mean latencies of the P1 and N1 components for DA trials of Pure, Mixed Feature and Mixed Block in both Likely and Certain temporal expectation of stimulus presentation.

NOTE: * = p < .05.

ERP locked to search stimulus onset: P1

In order to investigate whether and how temporal expectation and distractor expectations modulate early occipital activity in visual search leading to the selection of the target stimulus, P1 and N1 elicited by the search stimulus in DA trials were compared for the different type of distractor expectation (i.e., Pure block: no distractor expectation VS Mixed Feature block: expectation of distractor with no local contrast VS Mixed Conjunction block: expectation of distractor with high local contrast) and the different level of temporal expectation of search stimulus presentation (i.e., Likely vs Certain Temporal Expectation of stimulus presentation) (**Figure 6.3.2**). Mean amplitude of the P1 elicited in DA trials was submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Pure vs Mixed Conjunction block vs Mixed Feature block) and Temporal Expectation (Certain vs Likely) of search stimulus presentation. No main effect of Temporal Expectation (F (1, 22) = 1.7, p= .206) (**Figure 6.3.2 C**) and no interaction between Type of Block and Temporal Expectation were observed (F (2, 44) = 1.51, p=.233) (**Figure 6.3.2 A and D)**. We obtained a significant main effect of Type of Block (F (1.5, 33.1) = 9.15, p < .002), indicating that distractor expectation affects P1 in a differential way in the three blocks (**Figure 6.3.2 B**). In reason of such findings, we then verified whether the P1 enhancement is block-specific or generalized to all blocks. Therefore, we compared the mean amplitude of the occipital P1 of each block against zero with one-sample t-tests. Interestingly, the enhanced P1 was significant only in the Mixed

Feature (t (22) = 3.88, p < .001) and the Mixed Conjunction (t (22) = 8.07, p<.001) block but not in the Pure block (t (22) = 1.66, p=.106) suggesting a modulation of this early sensory perceptual stages of stimulus processing induced by distractor expectation (**Figure 6.3.2 B**).

Then we evaluated how the P1 amplitude is differentially modulated across the three blocks. Thus, we compared the mean amplitude of the occipital P1 of each block against the other blocks with paired-samples t-tests. These analyses revealed a significant enhancement of the P1 amplitude in DA trials of the Mixed Conjunction block as compared to both the Pure (t (22) = 3.08, p = .005) and the Mixed Feature block (t (22) = 1.17, p = .045). Finally, an almost significant enhancement of the P1 amplitude was elicited in the Mixed Feature block compared to the Pure block (t (22) = 1.94, p = .065) (**Figure 6.3.2 B**).

In order to evaluate whether temporal expectation and distractor expectation modulate the timing of the early occipital P1 component, mean peak latencies of the P1 elicited in DA trials were submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Pure vs Conjunction block vs Feature block) and Temporal Expectation (Certain vs Likely) of search stimulus presentation. No main effect of Temporal Expectation (F (1, 22) = 1.68, p= .208) (**Figure 6.3.2 C**), no main effect of Type of Block (F (2, 44) = .705, p= .499) (**Figure 6.3.2 B**), and no interaction between Type of Block and Temporal Expectation (F (2, 44) = .808, p=.452) were observed (**Figure 6.3.2 A and Figure 6.3.2 D**). These findings indicated that distractor expectation and temporal expectation do not modulate the timing of the occipital P1 component.

ERP locked to search stimulus onset: N1

We investigated whether and how temporal and distractor expectations modulated occipital N1 component elicited by search stimulus in DA trials. Mean amplitude of the N1 were submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Pure vs Conjunction block vs Feature block) and Temporal Expectation (Certain vs Likely) of search stimulus presentation (**Figure 6.3.2**). No main effect of Type of Block (F (1.44, 31.7) = 1.29, p= .280) was observed. Instead, a main effect of Temporal Expectation was observed (F (1, 22) = 27.66, p < .001), with a higher negativity of the N1 when the temporal expectation of search stimulus presentation was certain compared to when it was likely (**Figure 6.3.2 C**). No interaction between Type of Block and Temporal Certainty was observed (F (2, 44) = 1.48, p=.240), suggesting that the effect of Temporal Expectation does not significantly change across the three blocks.

Finally, we tested whether temporal expectation and distractor expectation modulate the timing of the occipital N1 component elicited by search stimulus of DA trials. Mean peak latencies of N1 were submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Pure vs Conjunction block vs Feature block) and Temporal Expectation (Certain vs Likely) of search stimulus presentation. No main effect of Temporal Expectation (F (1, 22) = 1.89, p= .183), no main effect of Type of

Block (F (2, 44) = .356, p= .703), and no interaction between Type of Block and Temporal Expectation (F (2, 44) = 2.658, p=.082) were observed, suggesting that distractor expectation and temporal expectation do not modulate the timing of the occipital N1 component (**Figure 6.3.2**)

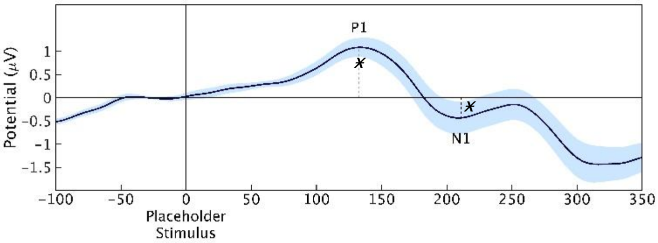

Figure 6.3.3: Search stimulus locked ERP over occipital electrodes averaged across all DA trials of all the blocks.

6.3.2 ERP locked to placeholder stimulus onset

Figure 6.3.4 shows the mean occipital ERP activity locked to the onset of the second and the third placeholder stimulus averaged across all DA trials of all the blocks. The ERP activity showed a significant positive deflection (t (22) = 8.06, p < .001) within the time window ~60-170 ms (mean peak latency: 132 ± 29 ms; mean amplitude 1.44 ± 0.86 μV). Moreover, this ERP activity showed a significant negative deflection (N1) in response to DA trials (t (22) = 2.67, p = .014) within the time window ~170-250 ms (mean peak latency: 198 ± 25 ms; mean amplitude -0.9 ± 1.62 μV) (**Figure 6.3.3**).

ERP locked to placeholder stimuli onset: P1

In order to discriminate preparatory early electrophysiological activity related to stimulus expectation (from that one related to stimulus presentation), the ERPs locked to the second placeholder stimulus (i.e., when no temporal expectation for search stimulus presentation is present) and the ERPs locked to the third placeholder stimulus (i.e., when a high temporal expectation for search stimulus presentation is induced) were compared for the three blocks. Thus, the occipital P1 elicited in DA trials were submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Pure vs Mixed Conjunction block vs Mixed Feature block) and Temporal Expectation (None vs Likely) of search stimulus presentation (**Figure 6.3.4**). No main effect of Temporal Expectation (F (1, 22) = 3.4, p= .078) was observed. Instead, a significant main effect of Type of Block (F (2, 44) = 7.02, p=.002) and a significant interaction between Type of Block and Temporal Expectation were observed suggesting that distractor expectation modulate N1 mean amplitude but this effect changes depending on temporal certainty of upcoming search stimulus (**Figure 6.3.4 A and Figure 6.3.4 D**). In reason of such findings, we evaluated whether the P1 enhancement is block-specific or generalized to all blocks. Thus, we compared the mean amplitude of the occipital P1 elicited by placeholder stimuli for all the conditions (2 conditions of Temporal Expectation X 3 conditions of Type of Block) against zero with one-sample t-tests. All comparisons were statistical significant (all p

<.001), indicating that in all the conditions a positive deflection was elicited by placeholder stimuli (**Figure 6.3.4 A)**.

In order to evaluate how the P1 amplitude locked to the placeholder stimuli was differentially modulated by temporal expectation across the three blocks, we compared the mean amplitude of the occipital P1 elicited in case of None temporal expectation with that elicited in case of Likely temporal expectation separately for each block. A significant enhancement of the P1 amplitude elicited by placeholder stimulus in condition of Likely (vs None) Temporal Expectation was observed only in the Mixed Conjunction block (t (22) = 3.66, p < .001), but not in the Mixed Feature (t (22) = .871, p=.393) and in the Pure block (t (22) = .538, p=.596), indicating that the P1 were differentially modulated by temporal expectation in the Mixed blocks (**Figure 6.3.4 D**).

In order to evaluate whether the P1 amplitude elicited by the placeholder stimulus was modulated by distractor expectation in the two conditions of temporal expectation, multiple paired-samples t-tests were performed to compare the P1 amplitude of each block against the other blocks separately for None and Likely Temporal Expectation. Interestingly, none of the comparisons performed in condition of None Temporal Expectation of search stimulus presentation were significant (Pure VS Mixed Feature: t (22) = 1.23, p = .231; Pure VS Mixed Conjunction: t (22) = .82, p = .421; Mixed Feature VS Mixed Feature t (22) = .563, p = .579). Instead, all the comparisons performed in condition of Likely Temporal

Expectation of search stimulus presentation reached statistical significance (Pure VS Mixed Feature: t (22) = 2.74, p = .012; Pure VS Mixed Conjunction: t (22) = 4.57, p < .001) or showed a trend toward the significance (Mixed Feature VS Mixed Conjunction t (22) = 1.8, p = .085). These analyses attested for an enhancement of the mean P1 amplitude elicited by the placeholder stimuli in the Mixed Feature block compared to the Pure block and in the Mixed Conjunction block compared to the other blocks (**Figure 6.3.4 A**). This indicates that a distractor-expectation enhancement of the P1 amplitude is not specific of visual search stimuli, but it is also elicited by other stimuli if an expectation for a visual search stimulus is induced in the subject.

Finally, we evaluated whether temporal expectation and distractor expectation modulate the timing of the early occipital P1 component elicited by placeholder stimuli. Mean peak latency of the P1 was submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Pure vs Conjunction block vs Feature block) and Temporal Expectation (Certain vs Likely) of search stimulus presentation. This analysis showed a significant main effect of Temporal Expectation on peak latency (F (1, 22) = 6.20, p= .021), with longer latencies of the P1 elicited by the placeholder stimulus in case of None Expectation for search stimulus presentation (compared to when the appearance of the search stimulus was Likely). No effect of Type of Block (F (2, 44) = 1.36, p= .268), and no interaction between Type of Block and Temporal Expectation (F (1.34, 29.44) = 1.43, p=.250) were observed, indicating that distractor-expectation does not modulate the effect of Temporal Expectation on the latency of the P1 (**Figure 6.3.4 C**).

ERP locked to placeholder stimuli onset: N1

In order to investigate whether and how temporal expectation and distractor expectation modulate occipital N1 component elicited by the placeholder stimulus, mean amplitude of the N1 were submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Pure vs Conjunction block vs Feature block) and Temporal Expectation (Certain vs Likely) of search stimulus presentation. No main effect of Type of Block (F (1.5, 32.5) = 2.6, p= .133), no main effect of Temporal Expectation (F (1, 22) = .66, p= .425) and no interaction between Type of Block and Temporal Expectation were observed (F (2, 44) = .59, p= .548), indicating that distractor expectation and temporal expectation of search stimulus presentation did not modulate the amplitude of the N1 elicited by placeholder stimuli (**Figure 6.3.4**).

Finally, we tested whether temporal expectation and distractor expectation modulate the timing of the occipital N1 component elicited by placeholder stimuli. No effect of Type of Block was observed (F (2,44) = .743, p = .482). Instead, a significant main effect of Temporal Expectation (F (1,22) = 12.05, p = .002) was shown with longer latencies of the N1 elicited by the placeholder stimulus in case of None Expectation for search stimulus presentation (compared to when the appearance of the search stimulus is Likely) (**Figure 6.3.4 C**). Finally, no interaction between Type of Block and Temporal Expectation (F (1.34, 29.44) = 1.43, p=.250) was observed, indicating that distractor-expectation did not modulate the effect of Temporal Expectation on the latency of the P1.

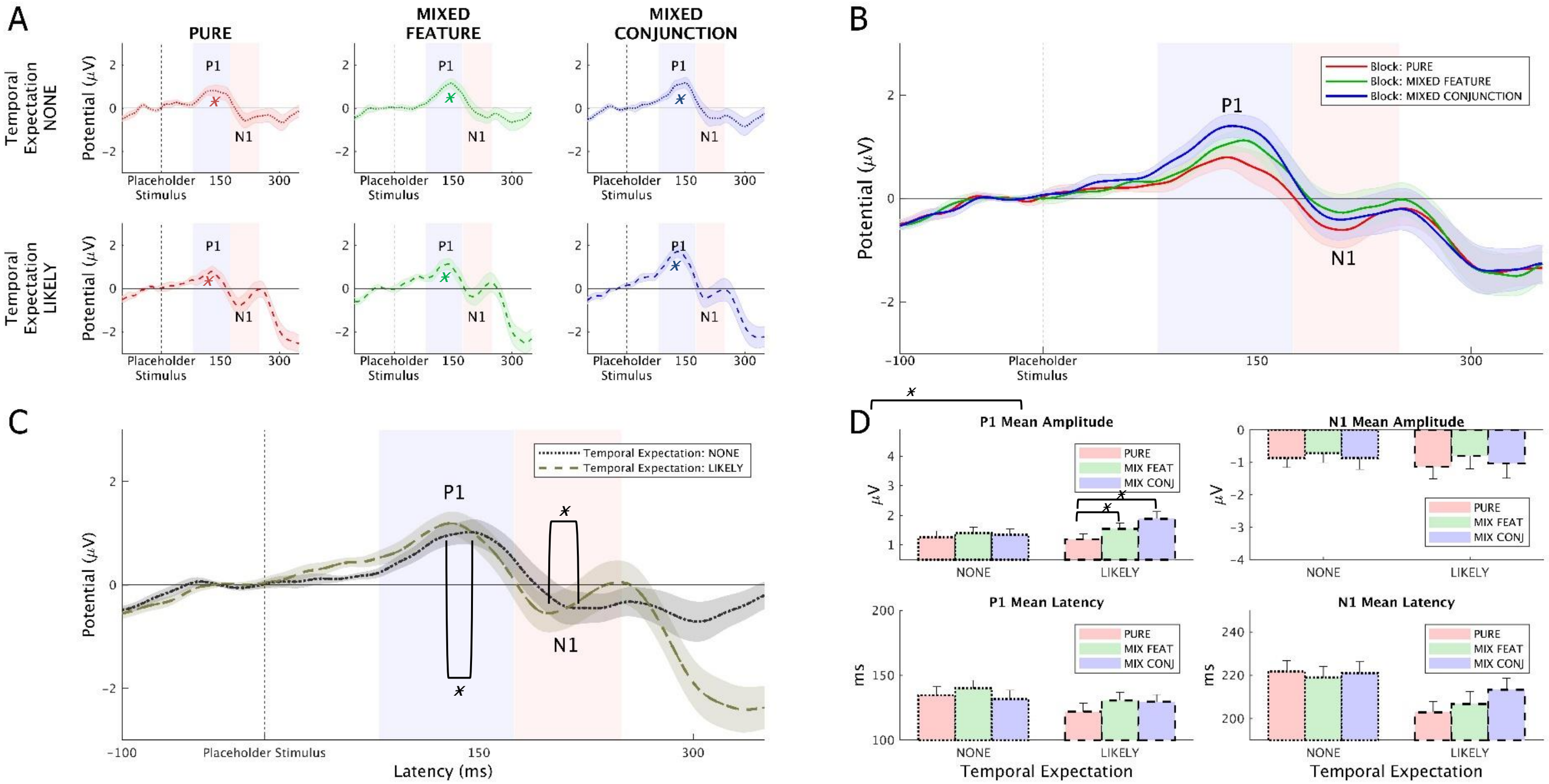

Figure 6.3.4: Early placeholder stimulus locked ERP activity over occipital electrodes for DA trials of Pure, Mixed Feature and Mixed Block in both Likely and Certain temporal expectation of stimulus presentation.

A) P1 and N1 components elicited in DA trials of Pure, Mixed Feature and Mixed Block in None and Likely temporal expectation of stimulus presentation. Shaded areas depict standard error B) Main P1 and N1 components in DA trials of Pure, Mixed Feature and Mixed Conjunction Block. Shaded areas depict standard error C) Main P1 and N1 components in DA trials of the conditions of None Temporal Expectation and Likely Temporal Expectation. Shaded areas depict standard error D) The graphs show mean amplitudes and mean latencies of the P1 and N1 components for DA trials of Pure, Mixed Feature and Mixed Block in both None and Likely temporal expectation of stimulus presentation.

NOTE: * = p < .05.

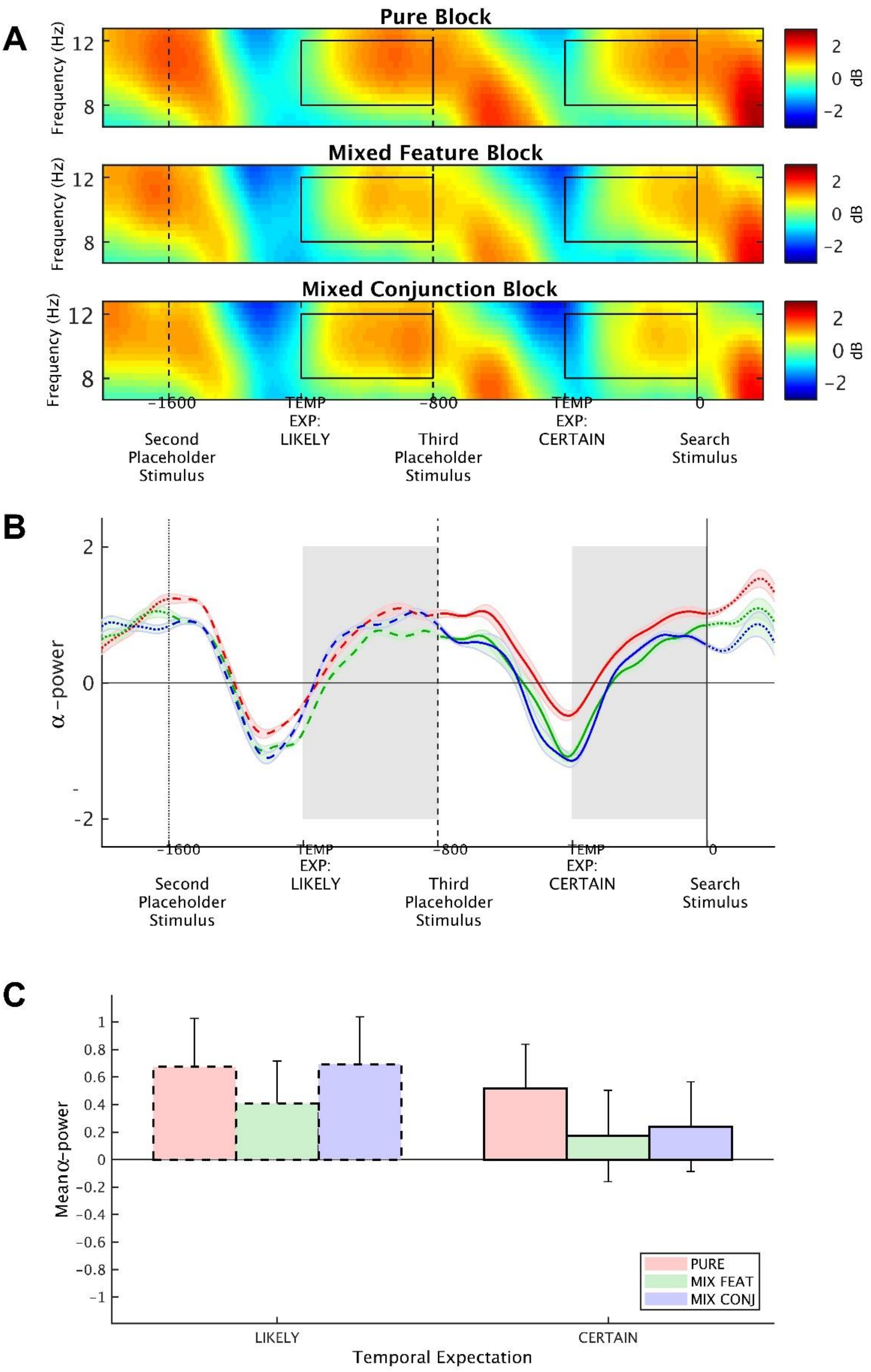

Figure 6.3.5: Alpha activity preceding the onset of the search stimulus. A) Color map showing the pre-stimulus (-1600 - 0 ms) mean ERSP (frequency 7-13 Hz) time-locked to the search stimulus for Pure, Mixed Feature and Mixed Conjunction block. B) Lines showing the average pre-stimulus alpha (8-12 Hz) perturbation for Pure, Mixed Feature and Mixed Conjunction block. C) Graph showing the average pre-stimulus alpha (8-12 Hz) perturbation time-locked to the search stimulus preceding the third placeholder stimulus (-200 - -800 ms) and the search stimulus (-400 - 0 ms) for Pure, Mixed Feature and Mixed Conjunction block

6.3.2 ERSP

Here we investigate whether and how distractor and temporal expectation modulate oscillatory brain activity related to anticipatory spatial attention. Mean alpha-band activity (8-12 Hz) just preceding (i.e., from -500 to 0 ms) the appearance of the third stimulus (i.e., when there is a likely expectation for the appearance of the search stimulus) and the fourth stimulus (i.e, when there is a certain expectation for the appearance of the search stimulus) were submitted to a repeated-measures ANOVA, testing the effect of Type of Block (Pure vs Conjunction block vs Feature block) and Temporal Expectation (Certain vs Likely) of search stimulus presentation (**Figure 6.3.5**). This analysis showed a significant main effect of Temporal Expectation on (F (1, 22) = 12.20, p= .002), with an increase in alpha activity in the time window preceding the third stimulus (i.e., 100% search stimulus) compared to the time window preceding the second stimulus (i.e., ~67% search stimulus) (**Figure 6.3.6**). No effect of Type of Block (F (2, 44) = 2.01, p= .147), and no interaction between Type of Block and Temporal Expectation (F (1.34, 29.44) = 1.43, p=.250) were observed, indicating that distractor-expectation did not significantly modulate the effect of Temporal Expectation on mean alpha power in these time windows.

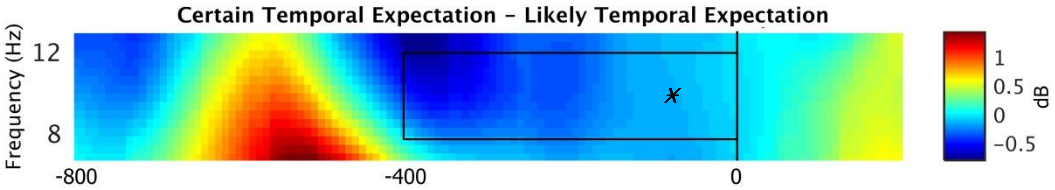

Figure 6.3.6: Color map of the ERSP between 7 and 13 Hz after subtraction of the time window of Likely Temporal Expectation (i.e., -1200 - -800 ms) from the time window of Certain Temporal Expectation (i.e., -400 – 0 ms).

The asterisk indicates that the difference is statistically significant (* p < 0.05) in the selected time and frequencies (i.e., rectangle: 8-12 Hz and -400 – 0 ms).

6.4 Discussion

In this chapter, we investigated whether the recruitment of proactive top-down processes of distractor expectation modulates the processing of sensory information in the visual system. In particular, we tested for distractor expectation related enhancement of occipital activity in early visual potential (P1 and N1) evoked by target and neutral stimuli at different levels of temporal certainty of upcoming search event.

Our results indicated that a distractor-expectation enhancement of the P1 amplitude was elicited both by search stimuli and neutral stimuli, but only when a temporal expectation for the appearance of a visual search stimulus is induced in the subject. Interestingly, this enhancement was observed not only when distractors are expected in the context of conjunction search but also in the context of feature search, suggesting that top-down expectation of distractors modulates bottom-up attentional capture at a sensory processing level. Moreover, this enhancement was modulated according to the expected task demands, being larger in context of conjunction search relative to feature search. On the contrary, we did not observe distractor expectation related modulation of the occipital N1 and alpha power. On the one hand, both of these electrophysiological markers followed the time course of temporal expectation. N1 was larger when elicited by a search stimulus in the condition of temporal certainty of its occurrence compared to when it is not certain. Alpha suppression was increased before a certain search event compared to when it was just likely. In contrast, N1 and alpha power activities did not seem to change as a function of the expectation of distractor.

Therefore, these results attested for an early attentional modulation on sensory visual areas induced by the recruitment of proactive top-down processes of distractor expectation. This attentional modulation was revealed during both feature and conjunction search.

CHAPTER 7

GENERAL DISCUSSION

Proactive top-down processes reflect the anticipatory maintenance of a specific control set in accordance with internally maintained behavioral goals (Braver, Paxton, Locke, & Barch, 2009; Begnoche, 2016). When conflicting inputs are expected to interfere with our goals, our cognitive set is proactively accommodated to prevent or minimize interference before it occurs. This is what was shown for example in a series of studies that adopted the DCM paradigm and unrevealed a proactive engagement of a distraction filtering mechanisms to minimize the interference determined by the incongruent distractors (Marini et al., 2013, 2015, 2016). So far, DCM paradigm has been applied to flanker task and crossmodal congruency task, but it has never been combined with visual search. Combining visual search and DCM paradigm could make a noteworthy contribution to unrevealing whether attentional capture in visual search is modulated by proactive top-down processes, an issue that is still controversial.

In order to investigate how the expectation of distractors lead to recruit proactive top-down mechanisms in visual search, and whether these mechanisms are recruited also in feature search, we combined two covert visual search tasks (i.e., a feature and a conjunction search task) with the Distraction Context Manipulation (DCM) paradigm (e.g., Marini et al., 2013) (Experiment 1). In line with previous studies in which DCM paradigm has been applied (Marini et al., 2013, 2015, 2016) our results revealed the recruitment of proactive top-down processes for distraction expectation by showing a slowing down of responses in those trials in which distractors were expected but not presented. This distractor-expectation cost was observed in both visual search tasks indicating that expectation for distractors recruits proactive top-down processes not only in conjunction search but, crucially, even in the context of feature search. Moreover, the distractor-expectation cost was smaller in the feature search compared to the conjunction search suggesting that expectation about the specific task demands modulates the magnitude of the activation of proactive top-down processes. It is worth to remark that these top-down processes are necessarily proactive. In fact, the effects of the distractor expectation are observed in distractor-absent trials of the Mixed blocks suggesting that they are recruited before incoming stimulus appears and as a consequence of the distractor expectation generated by distracting experiences occurred in previous trials.

However, results obtained in a covert visual search cannot be generalized to overt visual search (Palmer et al., 2011; Kiss et al., 2011). If the adoption of a proactive strategy could be adopted in covert visual search in order to be ready to discriminate the target stimulus in the short time available, a pure salience-driven capture may still represent a default mode in absence of such temporal demands (i.e., overt visual search). For this reason, in Experiment 2 we combined the DCM paradigm with two overt visual search tasks (i.e., a feature and a conjunction search task). Interestingly, this experiment replicated the pattern of response time obtained in the covert visual search. A distractor-expectation cost emerged in distractor-absent trials of both feature and conjunction search tasks and, again, this cost was smaller in the feature search and larger in the conjunction search. Together, results of Experiment 1 and 2 are incompatible with a pure saliency-driven theory of feature search because they demonstrate that expectation for distractors leads to the recruitment of proactive top-down processes in both overt and covert visual search; moreover, previous knowledge about expected task demands play a critical role in this process.

Beyond the presence of a proactive cost, Experiment 1 revealed also a beneficial effect caused by the recruitment of proactive top-down processes. In fact, in this experiment, a proactive enhancement of the detection sensitivity was revealed in contexts with expected distractors. This finding is consistent with a growing body of research that suggests that prior knowledge of the target-defining feature influences the sensitivity to the target (e.g., Serences, & Boynton, 2007; Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990; Chawla, Rees, &

Friston, 1999). A notable and potentially surprising aspect of these results was that, differently from RTs analyses, the modulation of the detection sensitivity did not depend on the specific type of distracting context. However, the latter result must be interpreted with caution: the lack of a significant difference in detection sensitivity between Mixed Feature and Mixed Conjunction block would be alternatively due to a possible ceiling effect, as suggested by the extremely low error rates achieved in distractor-absent trials of the Mixed blocks (i.e., Mixed Feature: TP-DA=1.4% of error; TA-DA=1% of error; Mixed Conjunction block: TP-DA=1.5% of error; TA-DA=0.5% of error).

Another question addressed in this work was whether the activation of proactive top-down mechanisms in visual search relies on phasic or tonic mechanisms. Marini et al., (2013) showed that the distraction-filtering mechanism could be activated either strategically or reactively depending on contextual circumstances. They manipulated the probability of distraction and they found that in context of high probability of distraction, the activation of the distraction-filtering was not modulated by the presence of distractors in the previous trial; while, under low distraction probability, a phasic activation of the distraction-filtering was triggered after infrequent distracting event occurred. In Experiment 1 and Experiment 2, we did not manipulate the probability, but the type of distractors. In these experiments, we found in both feature and conjunction search the same pattern of results, indicating that proactive top-down processes in visual search depend on both tonic mechanisms that are sustained throughout the potentially distracting sessions and, also, on phasic mechanisms that are contingently reinstated after a distracting experience occurred in a given trial. Interestingly, both the tonic and the phasic cost were larger in the context of conjunction search compared to the context of feature search, indicating that the activation of proactive top-down processes is dynamically adjusted to experienced and expected task demands.

Crucially, findings described above, showing the relevance of experience for the activation of processes for dealing with distractors, raised other important issues regarding the role of experience and expectation in the recruitment of proactive top-down processes. The first issue regards whether phasic experience-based top-down mechanisms for distractors expectation are under implicit or explicit control. Although such type of control mechanisms is triggered in an experience-driven manner, it is not clear whether top-down expectations play a mediating role in their recruitment. In order to address this question, in experiment 3 we assessed whether proactive top-down processes of distractor expectation are still recruited in distractor-absent trials if the occurrence of distractors is completely predictable (i.e., alternating distractor-absent and distractor-present trials). Maljkovic & Nakayama (1994) manipulated the predictability of the target feature and showed that predictable changes in the target color (e.g. alternating red and green over trials) produced RTs that were indistinguishable from unpredictable changes in target color (e.g. red and green target varied randomly over trials). Similarly, we found that the behavioral signatures of proactive top-down processes (i.e., the distractor-expectation cost and the detection sensitivity advantage) were found not only when distractor occurrence was unpredictable, but, crucially, persisted even when distraction occurrence was made predictable. These results suggest that the top-down control setting triggered by previous trial is not flexible and seems to be out of our explicit control.

Therefore, findings described above seem to suggest an important role of temporal proximity with previous distracting experience, but they cannot elucidate whether and how top-down expectations are implicated in visual search. What are the relative contributions of expectations to the recruitment of proactive top-down processes for dealing with distractors? Although Experiment 1 and 2 showed that a RT-cost emerged also in distractor-absent trials preceded by another distractor-absent trial, this effect could be alternatively explained as the result of a sustained activation of a specific control setting triggered by previous distracting experiences and that persists even after multiple distractor-absent trials. Experiment 1, 2, and 3 cannot establish a clear mediating role of top-down expectations on the recruitment of mechanisms for dealing with distractors. Experiment 4 sought to disentangle the relative contributions of previous distracting experience and distractor expectation by manipulating also another type of top-down expectation, that is the temporal expectation about when the search stimulus occurs. Temporal expectation about search stimulus appearance was manipulated on a trial-by-trial basis according to whether the certainty of upcoming search stimulus was likely or certain. Since, the temporal expectation of the search stimulus increased as the temporal proximity from the previous stimulus decreased, this paradigm was ideal to differentiate between those behavioral effects modulated by temporal expectation from those driven by previous distracting events. Recent studies highlighted a critical role of temporal expectations in modulating attention by enhancing the visual processing of task-relevant events (Griffin, Miniussi, & Nobre, 2001, Doherty et al., 2005, Praamstra, Kourtis, Kwok, & Oostenveld, 2006, Rohenkohl et al., 2011). Results of experiment 4 attested for a combined effect of expectation and experience in the activation and modulation of proactive top-down processes in distracting context. In particular, this experiment showed both in feature and conjunction search that the activation of proactive top-down processes is strongly modulated by top-down expectation about the type of search task, especially when these are coupled with temporal expectations about when the search event would occur. This study confirmed the key role of the presence of a distracting event in triggering proactive top-down processes in a reactive manner. In fact, the distractor-expectation costs were higher in distractor-absent trials preceded by a distractor-present trial. However temporal expectation played a greater role in the activation and modulation of this processes even in those trials preceded by a distracting event. In fact, the distractor-expectation costs followed the time course of temporal expectation even though the time course of temporal expectation varied inversely to the temporal proximity from previous distracting events.

A final question we assessed was whether proactive top-down mechanisms for distractors expectation modulate brain activity in sensory processing areas. Besides behavioral measurements, Experiment 4 used also event-related potential (ERP) and event related spectral perturbation (ERSP) measurements to investigate whether and how the recruitment of proactive top-down processes modulates pre-stimulus and post-stimulus occipital electrophysiological activity. Attention research has revealed that predictions about the locations or other features of relevant events can bias occipital neural activity starting from early stages of perceptual analysis of the visual stimulus (Luck, Chelazzi, Hillyard, & Desimone 1997; Posner & Gilbert, 1999; Gandhi, Heeger, & Boynton, 1999). Other studies have shown that anticipatory attention modulates oscillatory alpha band activity implicated in regulating occipital excitability before the appearance of the visual stimulus (Foxe, Simpson, & Ahlfors, 1998; Kelly, Lalor, Reilly, & Foxe, 2006; Thut, Nietzel, Brandt, & Pascual-Leone, 2006; O'Connell, Dockree, Robertson, Bellgrove, Foxe, & Kelly, 2009; Van Dijk, Schoffelen, Oostenveld, Jensen, 2008). In our study, the analyses of the early activity in occipital areas attested for a distractor-expectation enhancement of the P1 amplitude elicited by the target stimulus in distractor-absent trials. Interestingly, a P1 enhancement emerged also when neutral stimuli were presented, but only when a temporal expectation for the appearance of a visual search stimulus was induced in the subject. Moreover, this distractor-expectation enhancement was larger in conjunction search compared to feature search, indicating that it varies according to expected task demands. The P1 enhancement clearly provides evidence of early attentional modulation of sensory visual areas purely induced by distractor-expectation both in conjunction and feature search. On the other hand, no distractor expectation modulation of the occipital N1 emerged. Although this component was modulated by the degree of temporal certainty of upcoming search event, it was not modulated by distractor expectation. Similar results emerged also for the modulation of the occipital alpha power. An enhancement in alpha desynchronization emerged when the temporal expectation of upcoming search event was certain compared to when it was likely, but no significant modulation induced by distractor expectation emerged. However, it is worth noting that our paradigm cannot separate those modulations in alpha power related to preparatory attentional processes for target facilitation from those related to distractor suppression. If both alpha synchronization for distractor suppression and alpha desynchronization for target facilitation intervene during such type of tasks, their effects would be overlapped, limiting each other for emerging in EEG recording.

As Theueewes (2013) pointed out, previous studies that suggested a top-down modulation of attentional capture in feature search (e.g., Found & Müller, 1996; Wolfe, Butcher, Lee, & Hyle, 2003), could not rule out a possible effect of inter-trial priming. These studies showed that searching for a fixed target feature (i.e., the feature that defined the target remained the same for all trials) is faster than searching for a variable target feature (i.e., the feature that defined the target changed randomly from trial to trial) suggesting that knowing in advance the feature that defines the target benefits the search. In light of this, Theueewes argued that faster responses when the target feature remains constant (vs when the target feature varies from trial to trial) could be the results of a pure bottom-up priming of the target feature driven by what was selected in the previous trial (Theueewes, 2013). Differently from previous research, our results rule out this alternative explanation. In fact, in our experiments, the target remained the same in all the blocks and, given that an effect of inter-trial priming should affect equally all blocks, it cannot be responsible for the difference found between blocks. Even more important, the presence of a top-down tonic component of proactive processes is unexplainable by assuming any kind of inter-trial effects. In fact, the comparison between the Pure block and the Mixed blocks, which attested for a tonic top-down control, was based on equivalent distractor-absent trials that were identical also with respect the proceeding trial (i.e., another distractor-absent trial).

This is the first study in which visual search and DCM paradigm are combined. Besides replicating the finding of a proactive cost in distractor-absent trials of distracting context, the current results extended the validity of DCM paradigm to visual search, an attentional paradigm that differs in several ways from the tasks previously adopted. First of all, an important peculiarity of visual search tasks is that the selection is based on features and not on spatial location or sensory modality. In visual search, the spatial position of target and distractors items vary continuously and cannot be foreseen in advance. Differently, in previous experiments, target and distractor signals derived always from already known positions (i.e., arrow flanker task; Marini et al., 2013, 2015, 2016) or sensory modalities (crossmodal congruency task; Marini et al., 2013). This condition could allow to proactively prioritize and/or suppress the processing from definite spatial positions or sensory modality. Conversely, in visual search, it is not possible to proactively prioritize or suppress processing from specific spatial regions or sensory modality. Therefore, in this study, DCM paradigm has proved able to detect the recruitment of proactive top-down processes even in attention task in which previous knowledge about target and distractors locations (or sensory modality) are unavailable.

Another important peculiarity of visual search tasks adopted in this study is that distractors were not incongruent with the correct response, while, in the tasks previously adopted, incongruent distractors conveyed conflicting input interfering with the selection of the response. For instance, in the incongruent trials of the arrow flanker task (Marini et al., 2013, 2015, 2016) participants had to judge the direction of a centrally presented arrow while other arrows with opposite orientation flanked the relevant stimulus, thereby providing conflicting inputs. Similarly, in a variant of crossmodal congruency task (Marini et al., 2013), conflicting inputs were given by spatially incongruent visual distractors that interfered with a tactile elevation judgment. Instead, visual search does not imply such incongruency effect since distractors were not associated with incongruent response, thereby they did not convey any conflicting information interfering with the selection of the response. Moreover, the presence of a proactive recruitment of attentional processes even in search for a pop-out feature suggests that the mere expectation of distractors determine top-down attention recruitment regardless of whether distracting input have a negative impact on performance or not. Importantly, the fact that the behavioral and electrophysiological effects of this recruitment were stronger in context of conjunction search (vs feature search) suggests that this recruitment is not ‘all or nothing’ but is specifically calibrated to accommodate expected task demands.

However, it is worth noting that the findings of the current study cannot replicate the inverse relationship between the filtering cost (i.e., the difference in distractor-absent responses between the pure and the mixed block) and the distraction cost (i.e., the difference between incongruent distractor-present and congruent distractor-present trials of the mixed block) found by Marini et al. (2013; 2015; 2016). This inverse relationship suggested that “the more strongly one engages the mechanism to filter out potential distraction, the less his or her performance will be impaired when distraction actually occurs, and vice versa” (Marini et al., 2013). Here, the same relationship cannot be established since our paradigm did not include incongruent distractor and therefore the distraction cost cannot be computed. Therefore, the effect of proactive top-down recruitment cannot be directly related to a benefit in terms of RT when the distraction occurs. Similarly, this study cannot either highlight a potential relationship between the RT-cost and the d’-benefit. The current study was unable to analyze such type of relationship because of the presence of a ceiling performance in distractor-absent trials of the Mixed blocks that limited the variability detection sensitivity.

Although this study revealed the recruitment of proactive top-down processes both in feature and conjunction search, further works and analyses need to be done to characterize how proactive top-down processes of distractor expectation operate in visual search tasks. The observed increasing of detection sensitivity caused by distractors expectation as well as the presence of a response modulation at sensory processing areas would be interpreted as the result of attentional mechanisms for sensory processing facilitation of the attended target and/or suppression of attended distractors. However, it is worth noting that this study cannot clarify which type of preparatory control mechanism for distraction suppression (see paragraph 1.2) is adopted in visual search. Nevertheless, results of this study would tend to exclude the adoption of secondary inhibition as a unique preparatory mechanism for distractors suppression in visual search. In fact, secondary inhibition reflects a consequence of top-down target facilitation not specific for type of distractors. On the contrary, the modulation of the effects of distractor-expectation, consistently observed as a function of the type of distractor (Experiments 1,2,3, and 4), would suggest that a form of inhibition specific for type of distractor operates during this task. Moreover, at least one other non-attentional way of functioning of these proactive processes could intervene: the simultaneous slowing down of responses and the enhanced detection sensitivity caused by the expectation of distractors in distractor-absent trials could be also ascribed to proactive modulations of cognitive processes associated with decision making and motor control. Models of the speed-accuracy trade-off hold that speed, but inaccurate response occur when not enough sensory evidence has been accumulated to support an optimal decision (i.e., too low response thresholds) (Bogacz et al., 2006; for a review see

Heitz, 2014). From this perspective, variation of response time and detection sensitivity could reflect adjustments of response threshold to support accurate decision as a function of expected task demands. Therefore, in our experiments, the expectation of distractors could have determined an increase of the response threshold in order to augment the amount of sensory evidence accumulated before the response execution. Such processes would result in the improvement of accuracy as well as a slowing down of responses. So far, our analyses cannot clarify proactive top-down processes intervene at a decisional level.

Finally, an important limitation of this study regards the generalizability of results. As Wolfe (1998) pointed out, each visual search task is different, and findings emerged for one feature may not generalize to another. Therefore, further work needs to be done to establish whether the findings emerged in visual search for feature defined by local contrast are transferable also to other type of search tasks such as the search for stimuli defined by chromatic change, texture, motion and so on.

To conclude, it is important to emphasize that our results do not deny that relevant features in everyday life can automatically attract the attention without any top-down intervention. In fact, our results are specific of visual search. In everyday life, stimulus-driven reorienting of attention to behaviorally important objects is essential for the survival. In these situations, important unattended and unexpected objects can capture automatically our attention even when we are not going to look for them. Different is the case of visual search. When we are attending for impending stimuli several sources of previous knowledge (such as from instruction or from direct previous experiences) may be used to generate predictions of what to expect in incoming trials. In these cases, subject knows in advance its aim (‘look for a target’), its target and distractors (e.g. ‘look for the red item among green distractors’) or their defining characteristics (e.g. ‘look for a single odd-colored item among homogeneously colored distractors'). It follows that the cognitive set is proactively accommodated to better face with expected task demands. This is the case, not only in conjunction search, but crucially even in feature search, suggesting that the simple distractor expectation makes attentional capture not just exogenous but, also, endogenously modulated by top-down processes.

Let us now reconsider the example of the driver described in the introduction. The original question was whether irrelevant distractors on the side of the street lead to recruit proactive top-down processes for filtering them, and, whether their potential recruitment could affect the driving performance. In light of the findings of this study, the answer would be 'yes' to both questions. The visual experience (as well as the expectations based on previous experiences) of shop signs or billboards on the side of the street would recruit preparatory attentional process in order to optimize the processing of the relevant stimuli when presented in distracting context. Importantly, this recruitment will result also in a slowing down of the driver to react to an important signal even when it will appear alone, and no other distracting stimuli are simultaneously present in the visual scene. Interestingly, this phenomenon would manifest anyway, no matter how salient these irrelevant signals are. Nevertheless, the similarity between relevant and irrelevant signals would play a crucial role. The slowing down of the driver performance will plausibly increase as the similarity between the irrelevant item and important signals increases. Thus, it seems reasonable to expect that the time to react to red warning signals (e.g., red traffic light or the red tail light of the car preceding the driver) would heavily depend on the features of the irrelevant stimuli that the driver will meet: his performance would be much more impacted when frequent experience of red billboards of red shop signs are met during the driving compared to when the same signals are yellow and do not share distinctive features with the warning signals. If findings of this study would be generalizable to real environment they could have several implications that have not been considered so far.

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