Desensitizing the Attention System to Distraction While Idling: A New Latent Learning Phenomenon in the Visual Attention Domain

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For the good and the bad, the world around us is full of distraction. In particular, onset stimuli that appear abruptly in the scene grab attention, thus disrupting the ongoing task. Different cognitive mechanisms for distractor filtering have been proposed, but prevalent accounts share the idea that filtering is accomplished to shield target processing from interference. Here we provide novel evidence that challenges this view, as passive exposure to a repeating visual onset is sufficient to trigger learning-dependent mechanisms to filter the unwanted stimulation. In other words, our study shows that during passive exposure the cognitive system is capable of learning about the characteristics of the salient yet irrelevant stimulation, and to reduce the responsiveness of the attention system to it, thus significantly decreasing the impact of the distractor upon start of an active task. However, despite passive viewing efficiently attenuates the spatial capture of attention, a short-lived performance cost is found when the distractor is initially encountered within the context of the active task. This cost, which dissipates in a few trials, likely reflects the need to familiarize with the distractor, already seen during passive viewing, in the new context of the active task. Although top-down inhibitory signals can be applied to distractors for the successful completion of goal-directed behavior, our results emphasize the role of more automatic habituation mechanisms for distraction exclusion based on a neural model of the history of the irrelevant stimulation.

Keywords: attentional capture, distractor filtering, habituation, passive viewing

Human behavior, including our hidden (covert) mental activities, is subject to frequent distraction. Although this often turns out to be just an annoying circumstance, in other cases distraction can have more serious consequences. But why does distraction happen, and how does our brain cope with it?

The term "distraction" comes from the Latin verb *distrahere,* which means "to draw apart," and refers specifically to the fact that attention is diverted from its current focus. Indeed, while attention can certainly be voluntarily allocated to a given object according to our goals (Posner, 1980), salient stimuli often capture attention automatically (Jonides, 1981), despite our intentions, thus causing distraction. The reason why the attention system shows a high sensitivity to salient stimuli, like for instance onsets (Folk & Remington, 2015; Yantis & Jonides, 1984) or color-unique stimuli (singletons; Theeuwes, 1992; Turatto & Galfano, 2001), is that they signal conspicuous events that could be of motivational significance, and by giving immediate processing priority to these stimuli the organism can quickly inspect them and react appropriately. However, this attentional bias toward salient elements also makes us vulnerable to irrelevant distractors, which by capturing attention disturb the analysis of relevant information. It then becomes important to understand how we deal with distraction, namely whether the cognitive system is equipped with specific mechanisms to counteract the disrupting effects of irrelevant but salient stimuli that interfere with target processing, especially when the same distractors are recurrently encountered (Neo & Chua, 2006; Pascucci & Turatto, 2015; Turatto & Pascucci, 2016).

Although the filtering of unwanted information has long been proposed to be a core function of attention (Desimone & Duncan, 1995; Fries, Womelsdorf, Oostenveld, & Desimone, 2008), only recently has research focused on understanding to what extent distractor filtering is under strategic top-down control and intimately related to the goal of ensuring adequate performance even

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This study was supported by funds to Massimo Turatto from the Center for Mind/Brain sciences (CIMeC) of the University of Trento. Leonardo Chelazzi was supported by funding delivered within the "Ricerca di Base 2015" granting program of the University of Verona (grant B32F15000700001) and by funding from the Italian Government (Ministero dell'Istruzione, dell'Università e della Ricerca; Bando PRIN 2015).

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in the face of strong distraction (Awh, Matsukura, & Serences, 2010; Bonnefond & Jensen, 2013; Gaspelin & Luck, 2018; Geng, 2014). Different views have been developed highlighting key conditions under which efficient top-down filtering control can be applied to distractors during a goal-directed attention task. One prominent view assumes that in searching the visual environment for a given target, salient distractors can be effectively rejected if the observer adopts a top-down attentional set accurately tuned to the specific target defining features (Bacon & Egeth, 1994). Hence, in this case, distractor filtering would be the consequence of the adoption of a well-specified target template (Leber & Egeth, 2006b). In alternative, researchers have proposed that distractor filtering would be implemented by means of a direct top-down inhibitory control onto the distractors representation. According to this view, distractors are not simply ignored because of the adopted target template; rather, a specific top-down suppression strategy is applied to them to facilitate the analysis of behaviorally relevant stimuli (Dixon, Ruppel, Pratt, & De Rosa, 2009; Marini, Chelazzi, & Maravita, 2013; Müller, von Mühlenen, & Geyer, 2007). It should be noted that the latter filtering mechanism can take one of two forms: on the one hand, it can be engaged in a reactive manner, on the spur of the moment, in response to actual distraction (Geng, 2014; Marini et al., 2013; Marini, Demeter, Roberts, Chelazzi, & Woldorff, 2016; Vissers, van Driel, & Slagter, 2016); on the other, it can be recruited strategically in anticipation of expected distraction, for instance in response to a cue stimulus (cued distractor filtering) that informs the observer about the properties of a forthcoming distractor, such as its color or location (Cunningham & Egeth, 2016; Moher, Lakshmanan, Egeth, & Ewen, 2014; Munneke, Heslenfeld, Usrey, Theeuwes, & Mangun, 2011). Common to both views, however, is the key notion that the filtering of unwanted information takes place to protect target processing from interference. Put differently, distractor filtering would be functional to—and dictated by—the need of preserving successful target processing, an assumption that has reached a rather general consensus in the research community (Gaspelin & Luck, 2018; Geng, 2014; Marini et al., 2013; Moher et al., 2014).

Perhaps even more relevant to the present purposes, efforts have been made to characterize mechanisms of distractor filtering that critically depend on learning processes. For example, a number of studies have demonstrated that when distraction occurs frequently in a given context, and especially when it leads to conflict in triggering behavioral responses, cognitive systems are adjusted to better cope with such frequent distraction, in the form of a proactive and sustained mechanism to reject the distracting input (Geyer, Müller, & Krummenacher, 2008; Marini et al., 2013, 2016; Müller, Geyer, Zehetleitner, & Krummenacher, 2009). Interestingly, although the recruitment of this proactive mechanism is certainly beneficial when distraction does occur, at the same time such recruitment is costly in terms of overall performance when potential distraction is foreseen but does not actually materialize (Marini et al., 2013). Related to the above mechanism, researchers have also shown that the distractor filtering mechanism activated as a result of a learning process sensitive to the overall frequency of distraction (and conflict), is also sensitive to spatial contingencies in the distribution of distracting stimuli across the visual field, a phenomenon now known as statistical (or probability) learning of distractor filtering (Ferrante et al., 2018; Goschy, Bakos, Müller, & Zehetleitner, 2014; Leber, Gwinn, Hong, & O'Toole, 2016; Reder, Weber, Shang, & Vanyukov, 2003; Wang & Theeuwes, 2018). Therefore, the kind of proactive, learning-mediated filtering mechanism that is addressed in these studies is not only sensitive to the overall frequency of occurrence of distraction in a given context, but also to more subtle probabilistic contingencies regarding distractor occurrence. Importantly, however, and regardless of such nuances, it remains that in all conceptual developments that we are aware of, distractor filtering mechanisms—whether reactively or proactively engaged—are viewed as directly functional to shielding target processing in the face of potential or actual distraction, and this is true both when the given situation engages distractor filtering mechanisms as a result of ongoing processing of the visual input and when the same or similar mechanisms are engaged as a result of a learning process.

An alternative view on distractor filtering is offered by the notion of habituation, an ancestral form of learning consisting in a response decrement to repeated presentations of a non-noxious stimulus, and in which the decrement is not caused by receptor adaptation or motor fatigue (Groves & Thompson, 1970; Harris, 1943; Thompson, 2009). Although virtually the whole organism's response repertoire can be subject to habituation, of particular interest are previous studies, starting from the seminal work of Sokolov (1963), showing habituation of the orienting reflex (OR) toward irrelevant stimulation. As originally suggested by Pavlov (1927), the OR represents the orienting of attention toward a given stimulus with the purpose of identifying it, and traditionally, the OR has been operationalized as a set of changes in skeletal muscle responses (e.g., head and/or eye movements), visceral responses (e.g., skin conductance, blood pressure), and desynchronization of the EEG alpha activity caused by the new sensory input (Barry, 2009). However, with recurrent presentation of an innocuous and task irrelevant stimulus the OR habituates, namely all the physiological responses tend to return to the prestimulus level, which indicates that the organism is paying less and less attention to the repetitive input (Sokolov, 1963). As a possible mechanism to explain the habituation of the OR, Sokolov proposed the *stimulus-model comparator* theory, which essentially postulates that on the basis of the history of stimulation the brain progressively builds a neural model of the world, and each new sensory input is compared against such model. A mismatch between the input and the model generates an OR toward the new stimulus, whereas the closer the match between the input and the model, the more the OR is suppressed, which translates into habituation of the orienting of attention (Gati & Ben-Shakhar, 1990; Waters, McDonald, & Koresko, 1977). Hence, from this perspective, habituation reflects the functioning of a filtering mechanism to discard unwanted information, which prevents the continuous deployment of processing resources toward irrelevant, albeit salient, repetitive stimuli (Cowan, 1988). If habituation of the OR has mainly been studied by looking at overt orienting responses and to the corresponding changes in different physiological systems (Barry, 2009), habituation of attention can also be addressed by adopting paradigms that more specifically measure the contribution of covert attention, regardless of any other behavioral responses (e.g., vascular changes, heart rate, respiration, EEG arousal, etc.). For example, when participants are engaged in selective attention and memory tasks, the degree of interference from auditory distracting stimuli diminishes with practice, an observation that can be attributed to the habituation of attention capture evoked by the irrelevant information (Bell, Röer, Dentale, & Buchner, 2012; Elliott & Cowan, 2001; Kraut & Smothergill, 1978; Röer, Bell, & Buchner, 2014; Waters et al., 1977). Furthermore, other studies more specifically concerned with habituation of visuospatial attention capture have documented that the distracting property of sudden peripheral visual onsets diminishes as the exposure to the irrelevant distractors progresses (Neo & Chua, 2006; Pascucci & Turatto, 2015; Turatto, Bonetti, & Pascucci, 2018; Turatto & Pascucci, 2016), and that inhibition of return can be conceived as an instance of habituation (Dukewich, 2009). Analogously, previous studies specifically addressing the so-called *irrelevant-sound effect* have demonstrated that the disruption of serial recall of visual items by auditory distractors diminishes with practice, which has been interpreted as evidence of habituation of auditory attentional capture (Bell et al., 2012; Röer et al., 2014; Sörqvist, Nöstl, & Halin, 2012).

It should be noted that a Sokolovian-like mechanism for attention habituation is not implemented strategically, but instead is assumed to operate automatically on the basis of the history of stimulation, irrespective of any task set implementation (for a similar idea on the reflexive nature of the habituation mechanism also see Steiner & Barry, 2014). This is not to say, however, that habituation does not require attentional or working memory resources, because there is convincing evidence showing that working memory capacity affects the rate of habituation to irrelevant auditory distractors during visual-discrimination and memory tasks (Sörqvist, 2010; Sörqvist et al., 2012; Sörqvist & Rönnberg, 2014). Rather, the idea is that the habituation-dependent filtering mechanisms are not implemented strategically, in a goal-driven manner, to reject the distracting information. By contrast, as discussed previously, the shared view emerging from the visual attention literature is that mechanisms for distractor rejection are strategically implemented, with the specific aim to shield target processing from interference (Geng, 2014).

Hence, the aim of the present study was to investigate whether distractor rejection is mandatorily achieved via top-down inhibitory signals applied to distractors for the successful completion of goal-directed behavior, such as target discrimination, or alternatively whether a bottom-up habituation mechanism not necessarily tied to a concurrent discriminative task can account for the reduced distraction observed after repeated exposure to irrelevant peripheral onset stimuli.

To address this issue, in Experiment 1 we first measured how the distracting influence of peripheral onset stimuli diminishes as a function of practice while participants were engaged, for four "active" blocks of trials, in a fully focused attention task wherein they had to discriminate the orientation of a target line presented inside a cued circle (Turatto & Pascucci, 2016). Then, in Experiments 2, 3, 4, and 6, participants were merely exposed to the same distractors for two consecutive "passive" blocks of trials (i.e., in passive-viewing), before performing the discriminative task in two subsequent active blocks. The logic of the these experiments combined was as follows: If learning to filter the distractor is dictated by the need to shield target processing from interference, then the passive exposure phase should have no beneficial effects on the subsequent target discrimination phase, and any learning to enhance distractor filtering should start anew in the first active block of trials. By contrast, the habituation view would predict that participants should be able to capitalize on past experience acquired during passive viewing to promptly attenuate distraction once they become engaged in target processing. In other words, even during passive viewing, the system should learn that a stimulus is uninteresting and behaviorally irrelevant, therefore diminishing its impact on attention, even in the absence of a discriminative task. As already noted, that this might be the case is indeed suggested by previous studies showing that a passive exposure to irrelevant auditory stimuli prior to a visual task reduced their detrimental effects on subsequent performance (Bell et al., 2012; Elliott & Cowan, 2001; Röer, Bell, & Buchner, 2015; Waters et al., 1977). Indeed, in both Experiments 2 and 3 we found evidence to indicate that passive viewing exerted a beneficial influence on subsequent performance, in that interference generated by the irrelevant onset distractor was strongly diminished upon start of the active task, that is, following the two blocks of passive viewing. In each of the subsequent 4 experiments (Experiments 4 –7), we changed specific task parameters to better understand the nature of the habituation-like phenomenon shown in Experiments 2 and 3 and confirmed that learning to reject distractors can occur even when the system is not actively engaged in task performance and there is no need to shield target processing from distractor interference.

Experiment 1

As a first step, we wished to characterize the pattern of decay of the distracting effect caused by peripheral onset stimuli as a function of practice when participants were engaged, for four active blocks of trials, in a fully focused attention task wherein they had to discriminate the orientation of a target line presented inside a cued circle (Turatto et al., 2018; Turatto & Pascucci, 2016). Furthermore, because it is widely believed that peripheral onsets do not capture attention when the latter is fully focused in advance on a cued location (Theeuwes, 1991; Yantis & Jonides, 1990), the present experiments also served the purpose of replicating our previous findings by showing that, at least in the initial trials, fully focused attention is not immune to distraction caused by sudden peripheral onsets (also see Neo & Chua, 2006).

Method

Participants. Participants were 24 undergraduate students (17 female; mean age = 21.71 years) at the University of Trento and were recruited from the Department of Psychology and Cognitive Sciences for course credits or monetary compensation (8€). The participants set size of the present and the following experiments ranged from 18 to 24, a value that was chosen on the basis of our previous studies using a similar paradigm (Turatto et al., 2018; Turatto & Pascucci, 2016). Participants had normal or corrected-to-normal vision and were all naïve as to the purpose of the experiment, and all provided informed consent to participate in the present study. All the experiments were carried out in accordance with the Declaration of Helsinki, and with the approval of the local institutional ethics committee (Comitato Etico per la Sperimentazione con l'Essere Umano, Universita` degli Studi di Trento, Italy).

Apparatus. Stimuli were presented on a 23.6-in. VIEWPixx/EEG color monitor (1920 × 1080, 100 Hz) and generated with a custom made program written in MATLAB and the Psychophysics Toolbox (Pelli, 1997) running on a Dell Precision T1600 machine

(Windows 7 Enterprise). Eye fixation (or any eye movement) was monitored with an Eyelink 1000 Desktop Mount system (sampling rate: 1000 Hz; SR Research, Ontario, Canada).

Stimuli and procedure. Each trial began with the presentation of a fixation point surrounded by four circles positioned at the corners of an imaginary square (diagonal of 22.62°) centered on the fixation point (see Figure 1). The circles were light gray (7 cd/m^2) and were shown on a dark-gray background (0.07 cd/m^2). Three circles had the same thickness (inner diameter of 4°; outer diameter of 4.15°), whereas the thickest one (inner diameter of 4°; outer diameter of 4.25°) served as a spatial cue to indicate the position of the upcoming target (100% validity). The position of the cue was randomly assigned on each trial. After 1100 ms were elapsed, the target (31 cd/m^2), consisting of an oblique line tilted 45° either to the left or to the right, was presented within the cued circle for 100 ms.

On 50% of the trials, 100 ms before target occurrence, a high-luminance white annulus frame (inner diameter of 3.75°, outer diameter of 4.35°, 52.5 cd/m^2) was superimposed for 100 ms onto one of the three thinner circles, thus creating a sudden visual onset, which served as an attentional distractor. The position of the distractor relative to the target position was counterbalanced across trials. The display with the four placeholders remained onscreen until the participant's response or until 1500 ms were elapsed from the target onset. The next trial began after a variable interval, ranging from 1000 to 1200 ms from display offset, during which the screen was blank.

Participants were instructed to maintain fixation on the central point while focusing their attention exclusively on the cued target location (100% validity). The task was to report as quickly and as accurately as possible the orientation (left vs. right) of the target line by pressing the corresponding arrow on the computer keyboard. Response times (RTs) were recorded from the target appearance, and the maximum time allowed for responding was 1500 ms. Error feedback was provided by a message presented on the screen for 500 ms at the end of the trial.

The experiment consisted of four active blocks of 100 trials each. The term "active" indicates that a target discrimination task was performed on each trial of the block, whereas in other experiments (see below) two passive blocks of 100 trials each, in which no task had to be performed, preceded the two active blocks. Before starting the first active block participants performed a short block of 10 practice trials without the distractor. Task instructions and procedure, with information about the possible presence of the distractor in the active trials, were provided on screen before the beginning of the practice block.

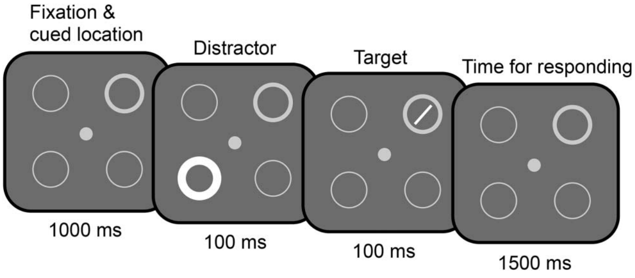

Figure 1. Schematic representation of the main events in the onset-present condition of Experiments 1, 2, 4, 5, and 6. The distractor (the bright annulus) appeared on 50% of the trials, and the target was a tilted line that always appeared inside the thickest stable circle (in this example, in the upright corner), which served as a spatial cue. In the passive-viewing condition the distractor was presented whereas the target was omitted (see Methods for details).

Results and Discussion

All the data and analyses reported in this and the following experiments regard the active blocks only, and the block of practice trials (when available), as these were the only blocks in which participants were engaged in target discrimination and performance could therefore be measured. For each participant, data on correct response trials were trimmed for RTs shorter than 150 ms (anticipations) or longer than 1000 ms.

In the present experiment, errors were ≤2% in each block and were not analyzed further, whereas the outlier-latency criterion removed less than 2% of the data. Attentional capture elicited by the distractor was defined as the reaction time (RT) difference between distractor-present and distractor-absent trials. A statistically reliable positive difference thus indicates that the distractor interfered with target processing by capturing visual attention.

RT differences (distractor-present minus distractor-absent) for correct responses were entered into an ANOVA for repeated measures with Block (four levels) as the only factor, which resulted in a significant effect, $F(3, 69) = 6.971$, $p < .001$, $^2 = .233$, indicating that the amount of attentional capture changed across blocks, as depicted in Figure 2 (top panel). Although capture was significantly larger than zero in all blocks ($p < .01$), pairwise comparisons (t test, two tails) confirmed that capture was significantly attenuated by practice: the degree of interference caused by the distractor in the first active block ($M = 44$ ms) was larger than in the second active block ($M = 28$ ms; $p = .030$), third active block ($M = 22$ ms; $p = .005$), and fourth active block ($M = 21$ ms; $p < .001$), respectively.

To provide a more detailed temporal analysis of the attentional capture reduction across blocks, we subdivided each block into 10 subblocks of 10 trials each (five distractor-present trials and five distractor-absent trials; see panels in the middle row of Figure 2). The RT differences were entered into an ANOVA for repeated measures with Block (four levels) and Subblock (10 levels) as the factors. The factor Block was significant, $F(3, 69) = 6.006$, $p = .001$, $^2 = .948$, whereas the factor Subblock, $F(9, 207) = .742$, $p = .670$, $^2 = .363$, and the interaction, $F(27, 621) = .906$, $p = .604$, $^2 = .803$, were not significant, thus indicating that the amount of capture did not change reliably within each block (i.e., across subblocks). Put it differently, this means that, as already noted, the reduction of capture occurred rather slowly along the experiment.

This pattern of capture was also confirmed by a *model fitting* approach. RT data (distractor-present minus distractor-absent) of each block were divided into 10 subblocks of 10 trials each. Data within each subblock were then averaged across participants and fitted to a negative exponential model of the form: $y_x = \alpha + \beta e^{(-x/r)}$, where x is the subblock index (ranging from 0 to 45, in bins of 5 trials), α is the RT plateau (the estimated RT value at the end of the block), β is the decay magnitude (the difference between RTs at the beginning and at the end of the block), and r is

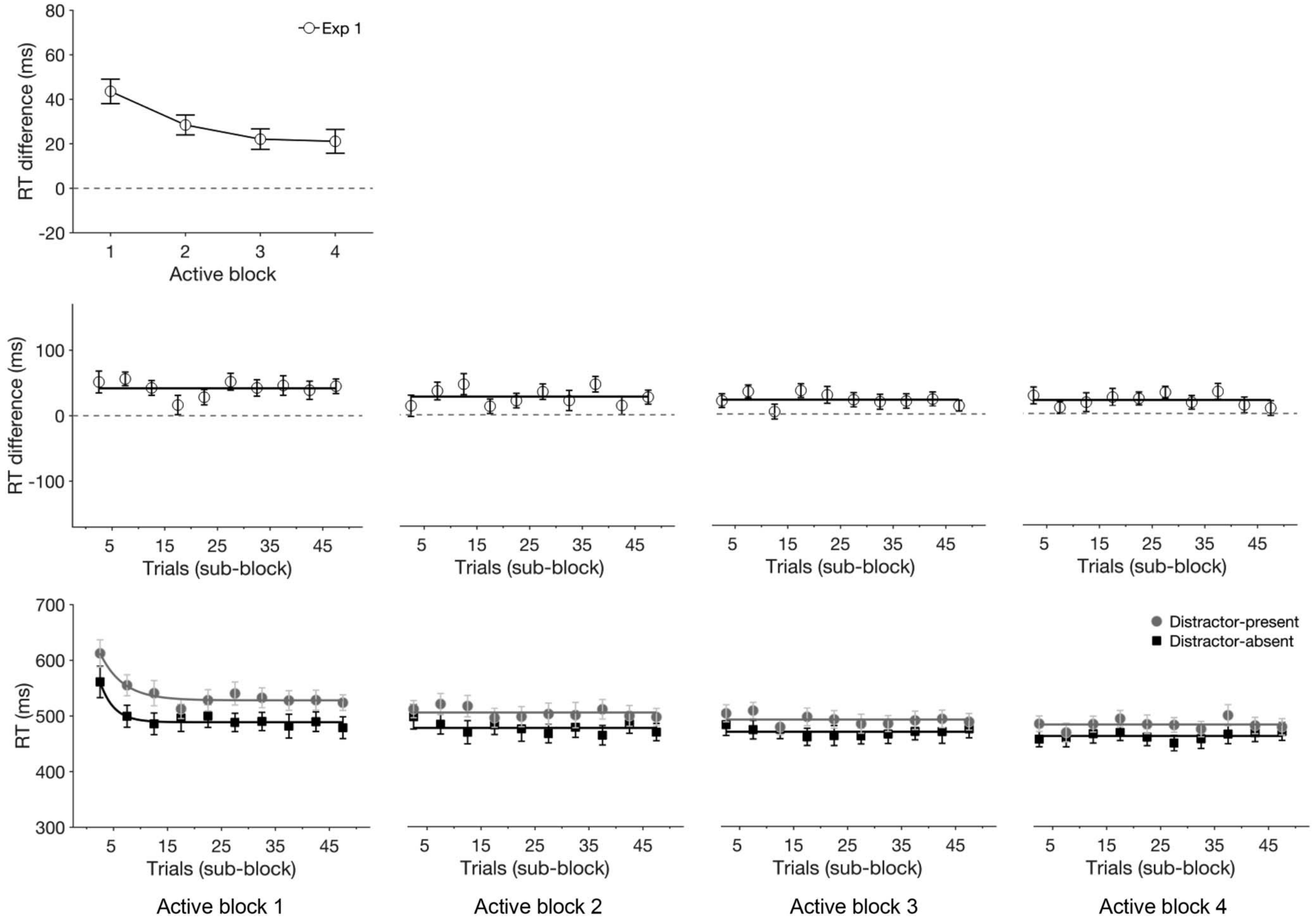

Figure 2. Top panel: attentional capture defined as the Response time (RT) difference between distractor-present and distractor-absent trials (present minus absent) as a function of active block. Each active block consists of 100 trials. Middle panels: attentional capture for each active block, in which RTs were divided in 10 subblocks of 10 trials each. Data points are plotted with their best-fitting model (a constant-only model). Bottom panels: absolute RTs in the distractor-present and distractor-absent conditions in each of the four active blocks, as a function of 10 subblocks. Data points are plotted with their best-fitting model: a negative exponential model for block 1, and a constant-only model for blocks 2 to 4. Bars represent ±1 *SEM*.

the time constant of the decay function (the smaller the r, the faster the RTs decay). The overall significance of the model was assessed through an *F* test, comparing the model fit against a constant-only model (i.e., a flat function) in which all the fitted values equaled a constant term (the mean of the response variable). When the *p* value of the *F* test was below $\alpha_{\text{crit}} = 0.05$, we rejected the null hypothesis that the exponential model does not provide a better fit than the constant-only model, indicating that the dependent variable (RTs) was approximately a negative exponential function of the independent variable (subblocks of trials). All models were estimated and evaluated with the *fitnlm* routine for nonlinear regression in Matlab.

In the present experiment the exponential model did not provide a better fit than a model with only a constant term (i.e., a flat function) in all active blocks (all $p > .5$), in agreement with the fact that capture was nearly constant across subblocks of a given block (see Figure 2, middle-row panels). However, in keeping with the prior observation that capture diminished slowly, that is, across blocks, a negative exponential function provided a better fit to the data when the analysis was repeated on all subblocks concatenated together ($y = 16.41 + 31.31e^{(-\text{subblock}/77.8)}$; $F(37) = 11, p < .001, R^2 = .37$).

To better characterize the time course of distractor interference, we decided that it was important to go one step further in analyzing task performance as a function of subblocks. In particular, instead of considering the distractor cost as such, we decided to separately look into the absolute performance for the distractor-present and distractor-absent conditions. In addition, we also planned to analyze task performance in the short block of 10 practice trials (without the distractor) that was performed before the first active block. Unfortunately, because of an error in the experiment code, these data were not saved, and therefore no such analysis was possible. Obviously the error was remedied in the subsequent experiments. As depicted in Figure 2 (bottom-row panels), average RTs decreased rapidly and to a similar degree in the distractor-present and distractor-absent conditions, with the two functions proceeding roughly parallel to one another along the 10 subblocks of the first block. Accordingly, a negative exponential model provided an excellent fit for both the distractor-absent ($y = 489.42 + 71.51e^{(-\text{subblock}/2.78)}$; $F(7) = 47.6$, $p < .001$, $R^2 = .93$) and distractor-present ($y = 527.42 + 86.57e^{(-\text{subblock}/5.14)}$; $F(7) = 39.1$, $p < .001$, $R^2 = .91$) conditions. By contrast, average RTs of both conditions stayed nearly constant across subblocks in the subsequent active blocks (2, 3, and 4), which was confirmed by the fact that the negative exponential model was not significant in any of the conditions (all $p > .05$). However, it is evident that average RTs for the two conditions were separated by an offset that diminished across blocks, reflecting the habituation-like phenomenon reducing capture by the peripheral onset as the experiment progressed. Therefore, the above analyses revealed the existence of two learning-dependent components: a first component, occurring equally in the distractor-absent and distractor-present conditions, which led to a robust speeding-up of performance within the first 20 or so trials of the first active block; and a second component that occurred selectively in the distractor-present condition and accrued slowly during the course of the entire experiment (as shown in the top panel). We interpret the first component as reflecting optimization of task performance, namely, optimization in the ability to select task-relevant information and in the stimulus-response mapping process, whereas we interpret the second as reflecting the slowly increasing ability to disregard the peripheral onset distractor, likely mediated by a habituation-like phenomenon.

The weakening of the distractor effect across blocks confirmed our previous findings, and could be accounted for by a mechanism of attentional capture habituation (Pascucci & Turatto, 2015; Turatto et al., 2018; Turatto & Pascucci, 2016). Alternatively, the reduction of capture as a function of training is also consistent with the possibility that participants learned to filter out the distracting stimulus to shield target processing from interference (e.g., Awh et al., 2010). However, if the latter is the mechanism at play, then a straightforward prediction follows: no learning of distractor filtering should take place when there is no target to be analyzed and no task to be performed. Such prediction was tested in the following experiments.

Experiment 2

In Experiment 2, to directly test the above prediction, for two initial blocks of trials participants were simply exposed to the distractor while maintaining central fixation (passive viewing). Then, two active blocks followed the passive blocks. Under these conditions, according to the strategic filtering account, no significant learning should take place during the initial passive blocks since no discriminative task is performed, and especially because participants had no expectation about the occurrence of the two subsequent active blocks. Consequently, attentional capture should be at full strength in the first active block requiring target processing. In other words, when the discriminative task was commenced at the start of the first active block, the amount of capture should be comparable to that found in the first active block of Experiment 1, while capture should then diminish in the next active block of trials.

Method

Participants. Participants were 24 undergraduate students (18 female; mean age = 21.29 years) at the University of Trento and were recruited from the Department of Psychology and Cognitive Sciences for course credits or monetary compensation (8€). They had normal or corrected-to-normal vision, and were all naïve as to the purpose of the experiment.

Apparatus. The apparatus used was the same as in Experiment 1.

Stimuli and procedure. The experiment consisted of two active blocks (100 trials each), with the same procedure of Experiment 1, which followed two initial passive blocks. In the passive blocks (100 trials each), the cue was presented but the target was not, and participants were asked to maintain fixation on the central spot, while passively viewing the display, which, on 50% of trials, included the peripheral onset. Before beginning the passive-viewing phase, participants were provided a description of the corresponding display. After the passive-viewing phase, participants received the new task instructions as in Experiment 1, and then performed a short block of 10 practice trials before starting the two active blocks.

Results and Discussion

Errors were 3% in the first active block, and 1% in the second active block (the difference was not significant, $p = .198$), and were not analyzed further. The ANOVA on the RT differences for correct responses revealed that the factor Block (two levels) was not significant, $F(1, 23) = 1.174$, $p = .290$, $^2 = .049$ (see Figure 3, top left panel); capture was significantly larger than zero in both the first ($p < .001$) and the second ($p = .005$) active block of trials. Crucially, however, in the first active block the amount of capture in this experiment ($M = 26$ ms) was significantly smaller than in Experiment 1 ($M = 44$ ms), $p = .018$ (independent-samples t test). By contrast, no significant difference emerged between the two experiments concerning the second active block ($p = .234$). Hence, as shown in Figure 3 (top left panel), the distractor cost during the first active block was strongly reduced in Experiment 2 relative to the first experiment, indicating that in the second experiment a learning process taking place during the initial two blocks of passive viewing had greatly reduced the ability of the distractor to later interfere with task performance. In turn, this indicates that the learning process occurs even within a context wherein the distractor is actually unable to exert any negative impact on performance for the simple reason that there is no task to be performed during passive viewing.

To strengthen the above conclusions, we decided to analyze in greater detail task performance during the active blocks of Experiment 2, as we did for Experiment 1. In particular, we initially focused on the subblocks of the first active block of trials, as this was the block in which the largest difference in terms of capture emerged between the two experiments. The RT differences were entered into an ANOVA for repeated measures with Sub-Block (10 levels) as the only factor, which resulted in a significant effect, $F(9, 207) = 4.154$, $p < .001$, $^2 = 0.153$. Pairwise comparisons (against zero) showed that capture in the first active block was reliable only in the first subblock of trials ($p < .05$, Bonferroni corrected for multiple comparisons, see Figure 3, top middle panel). This RT pattern was well fitted by a negative exponential

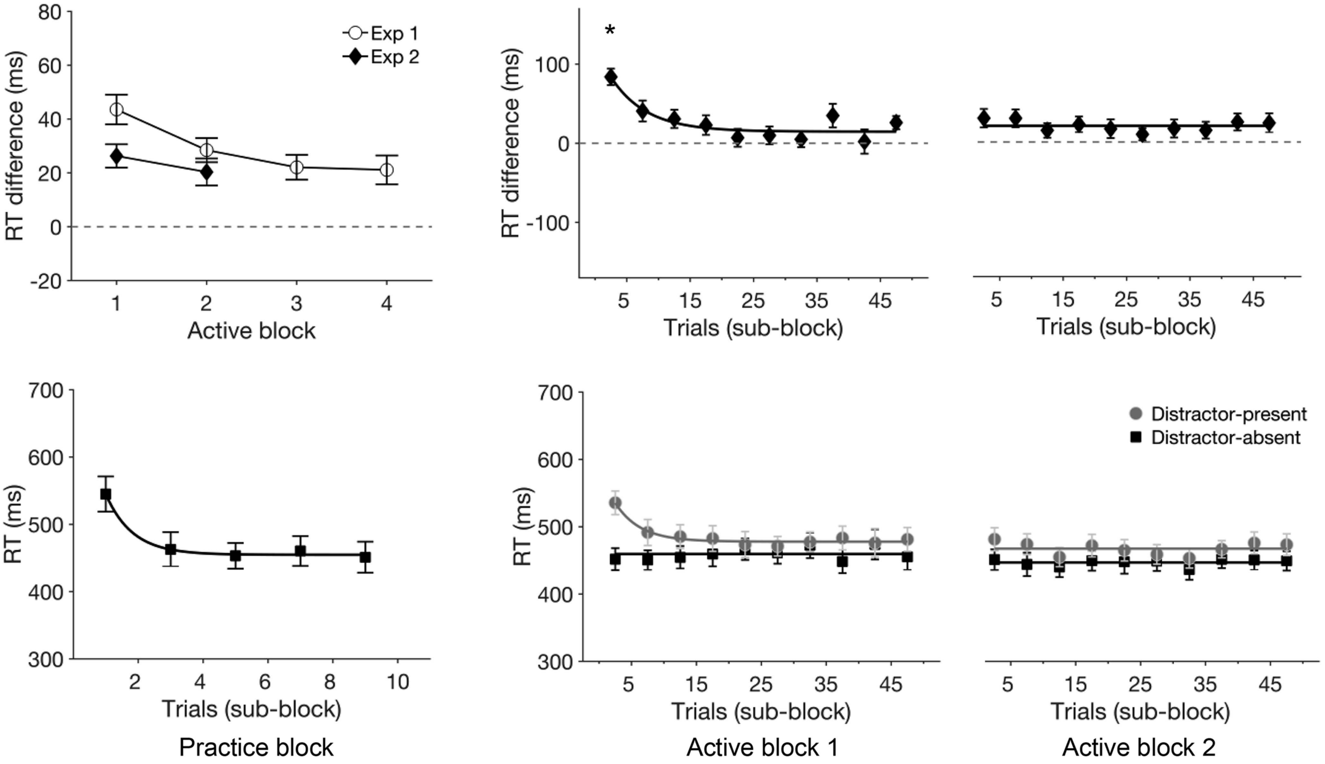

Figure 3. Top left panel: attentional capture as a function of active block in Experiments 1 and 2. Top middle and right panels: attentional capture as a function of subblock in the two active blocks. The asterisk indicates the subblock of trials in which capture was statistically significant ($p < .05$, Bonferroni corrected). Data points are plotted with their best-fitting model. Bottom panels: absolute Response times (RTs) in the distractor-present and distractor-absent conditions in the practice block (distractor-absent condition only) and the two active blocks. Data points are plotted with their best-fitting model. Bars represent ±1 *SEM*.

function (model equation: $y = 14.68 + 68.83e^{(-\text{subblock}/5.57)}$; F statistic vs. constant model, $F(7) = 15.9$, $p = .002$, $R^2 = .82$), thus confirming a rapid decay of capture that reached asymptotic values after about 20 trials. By contrast, in the second active block the factor Subblock was not significant, $F(9, 207) = .466$, $p = .896$, $^2 = .227$, and accordingly the RT pattern was better described by a flat function, $F(7) = .52$, $p = .588$, $R^2 = .14$.

However, regardless of whether within the first active block capture remained roughly constant, as we found in Experiment 1, or rapidly declined, as found in the present experiment, it is important to underscore that in the present experiment the cost at the asymptotic level was significantly reduced relative to Experiment 1. This key finding, which is indicative of an overall reduction of the distractor interference cost in the second experiment relative to the first, clearly demonstrates that the passive-viewing phase substantially attenuated the overall amount of capture as soon as the active task commenced. However, despite such clear reduction in capture, inspection of Figure 3 (top middle panel) also seems to indicate that in Experiment 2 the distractor onset was transitorily able to capture attention at the beginning of the discriminative task. In fact, in the 1st subblock capture appears to be even larger here than in Experiment 1, though the difference is not statistically significant ($p = .105$, independent-samples t test). The reason for what appears to be a relatively strong, albeit transient, capture effect at the start of the active task will become evident in the following section.

When data were analyzed for the distractor-present and distractor-absent conditions separately, the results showed that within the first block average RTs stayed nearly constant across subblocks in the distractor-absent condition, whereas they started relatively high and then underwent a rapid drop over subsequent subblocks in the distractor-present condition. The two different patterns were confirmed by the fact that the negative exponential model was not significant for the distractor-absent condition, $F(7) = 1.13$, $p = .377$, $R^2 = .24$, whereas it nicely fitted the data in the distractor-present condition ($y = 477.81 + 57.51e^{(-\text{subblock}/3.84)}$; $F(7) = 73.4$, $p < .001$, $R^2 = .95$). In the second active block both RT patterns were fitted well by a flat function ($p > .05$ in both conditions). In addition, as depicted in Figure 3 (bottom left panel), a negative exponential model provided a good fit for the practice trials of Experiment 2 ($y = 454.73 + 90.20e^{(-\text{subblock}/0.82)}$; $F(2) = 129$, $p < .001$, $R^2 = .99$). This pattern was substantiated by an ANOVA for repeated measures with Subblocks (five levels) as factor, which was significant, $F(4, 72) = 11.175$, $p < .001$, $^2 = 1$.

The overall pattern of results provides some important indications. First, during the initial block of practice of this experiment, in which the distractor was never presented, a few trials were sufficient to reach asymptotic performance in the discriminative task, with the initial deceleration in RTs reflecting rapid optimization in the ability to select task-relevant information and in the stimulus-response (S-R) mapping process, or more generally, familiarization with the discriminative task. This explains why, in Experiment 2, when the first active block started, the RT function in the distractor-absent condition stayed flat throughout. Actually, the same pattern should have emerged also in Experiment 1, but this was not the case. One likely possibility is that, in Experiment 1, the block of practice trials was not sufficient to allow participants to reach asymptotic efficiency in the above processes, including S-R mapping. As a consequence, in that experiment, at the beginning of the first active block, RTs in the first subblock were still higher than in the following subblocks.

Second, the flat RT function that we found in the distractor-absent condition of Experiment 2 provides a straightforward explanation for the apparently larger capture observed in the initial trials of this experiment as compared with Experiment 1. Because capture is defined as the RT difference between distractor-present and distractor-absent trials, the fact that in Experiment 2 the RTs function in the distractor-absent condition remained nearly constant across the whole block, whereas it was negatively accelerated in Experiment 1, explains why the amount of capture in the 1st subblock of trials appears to be artificially magnified in the former experiment.

Third, when the RT cost caused by the distractor is evaluated at the asymptotic level (i.e., from subblock 5 to 10), a significant reduction of capture is observed in the present experiment relative to Experiment 1, and this occurs as the result of the passive-viewing phase. However, although the passive-viewing phase was clearly effective in reducing the overall amount of capture, and in particular the amount of capture at the asymptotic performance level, it remains to be explained why the distractor still exerted a strong, albeit transient, effect on RTs at the beginning of the first active block. Indeed, one could have predicted habituation of capture occurring during passive viewing to strongly reduce any detrimental effect on RTs from the very beginning of the first active block. This and other related issues will be investigated in the next experiments.

Experiment 3

The results of Experiment 2 show that the mere exposure to an irrelevant attention-grabbing onset during passive viewing ameliorates the filtering of such stimulus when later on it competes for attention with a target. This suggests that the cognitive system initiates the process supporting distractor filtering even in the absence of an active task. Such process is likely to build a neural model of the distractor and its contextual occurrence despite no discriminative task is performed during passive viewing, so that the learned distractor-related information is used later to rapidly shield target processing from interference upon start of the active task. However, as already noted, in principle learning-dependent distractor filtering could be fully implemented before target presentation, so that the distractor impact should be minimal (or totally prevented) from the outset of the discriminative task, namely from the beginning of the first active block. Instead, we found that in the first few trials of the active block of Experiment 2 the distractor apparently retained its full capacity to capture attention, just like in Experiment 1, a result that can be accounted for by alternative explanations.

One possibility is that the negative exponential RT function observed in the distractor-present condition might indicate that the S-R mapping process, already optimized during the practice trials, needs to be relearned in the new context defined by the distractor presence. We actually think that this explanation is very unlikely because, if this were the case, then one should predict to find a similar pattern also in the distractor-absent condition, which is clearly not the case. In fact, should the S-R mapping be relearned within the new context, namely a task paradigm wherein a salient distractor is presented on half the total trials, this ought to impair performance to a similar degree in the distractor-absent and distractor-present condition. Therefore, we think it is safe to reject this possibility. Another context-related possibility is that although information concerning the distractor was latently learned during passive viewing, leading to an attenuated orienting response, the distractor briefly captured attention when presented in the context of a new discriminative task. In other words, although the learning-dependent process supporting distractor filtering can take place during passive viewing, the appearance of the distractor during target discrimination may cause an initial cost because participants need to get used to handling the distractor in the new context of the active task. It should be noted, however, that the transient cost does not necessarily reflect a spatial attention shift away from the cued location, which, in our view, is more likely indexed by the RT difference at the asymptotic level. Rather, the initial lengthening of RTs in the distractor-present condition may reflect an object-based competition between the distractor and the target (Duncan, 1984; Treisman, Kahneman, & Burkell, 1983; van Boxtel & Koch, 2012), given that the target was never experienced before by participants. At any rate, whatever the nature of this cost, it is clear that it dissipates in a few trials, unlike the typical capture effect that takes many tens of trials to asymptote (see Figure 2, top left panel). In other words, distractor filtering is effectively achieved only after some initial trials requiring target discrimination.

Yet a different explanation also assumes that by the end of the passive-viewing phase the learning-dependent process supporting efficient distractor filtering was indeed fully implemented; however, this view postulates that the initial lengthening of RTs in the distractor-present condition is attributable to a conflict, between the target and the distractor, that emerges specifically because both elements share the crucial feature of being onset stimuli. In other words, at least initially the visual system would need to solve a sort of contingent-capture effect (Folk, Remington, & Johnston, 1992), which renders the system temporarily vulnerable to the onset distraction.

To exclude the latter possibility, in the present experiment the target did not share with the distractor the property of being an onset stimulus, at least in a strict sense. Instead, the no-onset target was shown as a line segment rotating around its center, which at a certain point in time stopped its rotation, thus becoming a tilted line as in the previous experiments (see Figure 4). The rotating line was presented also during the passive-viewing phase, with the line continuing to rotate until the end of the trial. By contrast, during the discriminative task the target was a tilted line, revealed by the end of a circular rotatory signal, whereas the distractor was an onset stimulus as in the previous experiments. Under these conditions, if distractor filtering is fully accomplished during passive

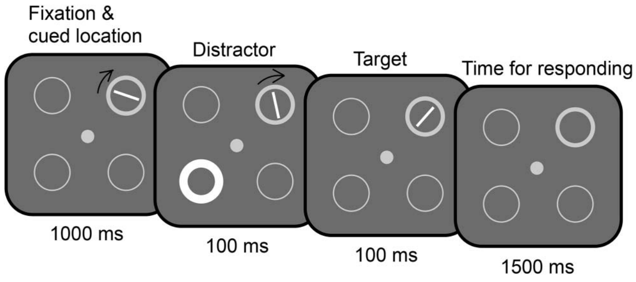

Figure 4. Schematic representation of the main events in the onset-present condition of Experiment 3. The distractor (the bright annulus) appeared on 50% of the trials, and the target was a tilted line that always appeared inside the thickest stable circle (in this example in the upright corner), which served as a spatial cue. The target was revealed when the rotating line came to a stop. During the passive-viewing phase the rotating line was presented but never came to a stop.

viewing, and the lengthening of RTs found in the first subblock of Experiment 2 was attributable to an initial phase necessary to resolve competition between the two onset stimuli, then such effect should disappear in the first active block of the present experiment. Conversely, the effect should still be observed in the initial trials of the first active block if it reflects any of the factors that we have considered above.

Method

Participants. Participants were 24 undergraduate students (19 female; mean age = 22.71 years) at the University of Trento and were recruited from the Department of Psychology and Cognitive Sciences for course credits or monetary compensation (8€). They had normal or corrected-to-normal vision, and were all naïve as to the purpose of the experiment.

Apparatus. The apparatus used was the same as in Experiment 1.

Stimuli and procedure. These were the same as in Experiment 2, namely the two active blocks were preceded by two passive-viewing blocks, but with the following exceptions. First, during the passive blocks the thicker circle contained a rotating line (rotation speed 500°/s) that remained on screen till the end of the trial. Participants were asked to maintain fixation on the central spot, while passively viewing the display. Second, during the discriminative task in the active blocks, 1100 ms after the display onset the line stopped its rotation either at 45° or −45° from the vertical axis, thus revealing, for 100 ms, the same tilted-line target as in the active blocks of the previous experiments.

Results and Discussion

Errors were 3% in the first active block and 2% in the second active block (the difference was not significant, $p = .332$), and were not analyzed further. The results on RTs closely matched those of Experiment 2 (see Figure 5, top left panel). When the RT differences for correct responses were analyzed as a function of block, the ANOVA showed that the factor Block (two levels) was not significant, $F(1, 23) = .235$, $p = .632$, $^2 = .010$, as capture was significantly larger than zero in both the first ($p = .011$) and the second ($p = .003$) active block of trials. The amount of capture in the first active block ($M = 25$ ms) was smaller than in the corresponding block 1 of Experiment 1 ($M = 44$ ms), although the difference only approached significance in this case, $p = .089$ (two tails), whereas no difference emerged between the two experiments in the second active block ($p = .474$).

As before, we then conducted a fine-grained temporal analysis of attentional capture in the active blocks of Experiment 3. The results (see Figure 5, top middle and right panel) were very similar to those found in Experiment 2, and showed that in the first active block the factor Subblock (10 levels) was significant, $F(9, 207) = 3.196$, $p = .001$, $^2 = .122$, with capture decreasing significantly across subblocks. Pairwise comparisons showed that capture was reliably present only in the initial trials of the first active block (1st and 2nd subblocks, all $p < .05$, Bonferroni corrected), and then rapidly disappeared in the following part of the block (with the exception of the 5th subblock). Accordingly, this RT pattern was well fitted by a negative exponential function ($y = 17.82 + 69.35e^{(-\text{subblock}/3.83)}$; $F(7) = 5.88$, $p = .031$, $R^2 = .62$). In the second active block, instead, the factor Subblock was not significant, $F(9, 207) = .653$, $p = .751$, $^2 = .318$, and the RT pattern was better described by a flat function, $F(7) = 1.38$, $p = .31$, $R^2 = .28$.

Data were also analyzed by considering RTs in the distractor-present and distractor absent conditions separately across subblocks (see Figure 5, bottom panels). In particular, in the first active block average RTs stayed constant across subblocks in the distractor-absent condition, whereas they showed a negatively accelerated function in the distractor-present condition. The two different patterns were confirmed by the fact that the negative exponential model was not significant for the distractor-absent condition, $F(7) = .10$, $p = .905$, $R^2 = .02$, whereas it nicely fitted the data in the distractor-present condition ($y = 541.75 + 65.23e^{(-\text{subblock}/4.04)}$; $F(7) = 8.84$, $p = .012$, $R^2 = .71$). On the contrary, in the second active block both RT functions were flat ($p > .05$). In addition, as depicted in Figure 5 (bottom left panel), a negative exponential model provided a good fit for data from the practice trials ($y = 534.82 + 142.26e^{(-\text{subblock}/1.75)}$; $F(2) = 161$, $p < .001$, $R^2 = .99$). The RTs decay across subblocks was confirmed by an ANOVA for repeated measures with Subblock (five levels) as factor, which was significant, $F(4, 68) = 10.057$, $p < .001$, $^2 = 1$. This confirmed that the practice block was sufficient to allow participants to optimize processes related to efficient selection of task-relevant information and S-R mapping, in turn allowing asymptotic performance at the task in the absence of the distractor.

The pattern of results from the present experiment, where the target was a no-onset element, excludes the possibility that the slowing down of RTs that we found in the initial trials of Experiment 2 (distractor-present condition) was attributable to the similarity between target and distractor in sharing the onset property, thus leading to a form of contingent capture (Folk et al., 1992). Rather, the results leave open the possibility that the transient cost in performance observed in the early trials of both Experiments 2 and 3 (distractor-present condition) is caused either by the need to transfer any learning, related to distractor filtering achieved during passive viewing, to the new context defined by the discriminative task, or by the need to relearn, or reoptimize, the S-R mapping in the presence of the distractor, although we have already argued that the latter possibility is very unlikely (see above). Finally, the

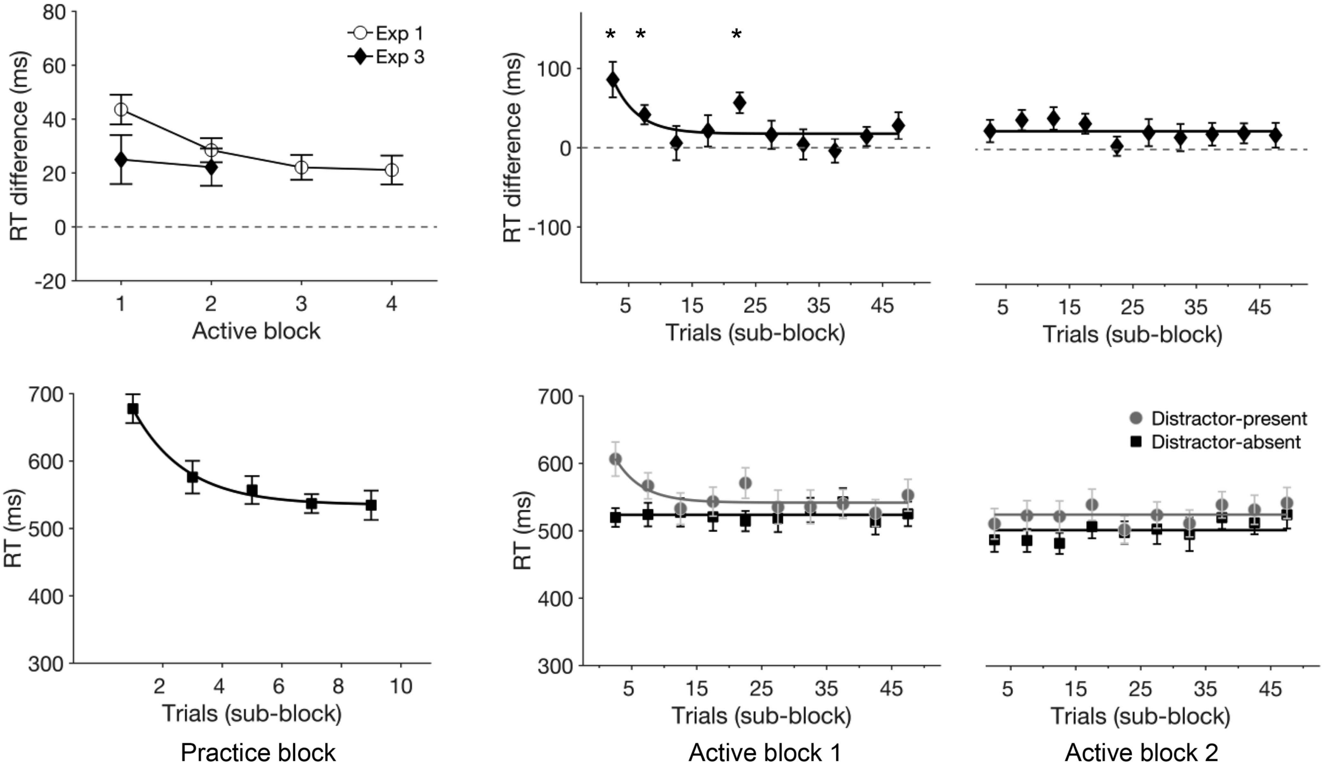

Figure 5. Top left panel: attentional capture as a function of active block in Experiments 1 and 3. Top middle and right panels: attentional capture as a function of subblocks in the two active blocks. Asterisks indicate the subblocks of trials in which capture was statistically significant ($p < .05$, Bonferroni corrected). Data points are plotted with their best-fitting model. Bottom panels: absolute Response times (RTs) in the distractor-present and distractor-absent conditions in the practice block (distractor-absent condition only) and the two active blocks. Data points are plotted with their best-fitting model. Bars represent ±1 *SEM*.

possibility remains that the initial lengthening of RTs is caused by a sort of short-lived object-based competition between the target and the distractor.

In addition, and very importantly, the results also confirm what we found in Experiment 2, namely that at the asymptotic performance level attentional capture is strongly attenuated, which suggests a highly beneficial influence of the passive viewing phase in learning to resist distraction. In sum, evidence from the last two experiments combined indicates that, because of experience gained during the preceding passive-viewing phase, the system quickly adjusts to ignore the distractor as soon as the active task begins. Such distractor rejection process, however, is transiently perturbed when the discriminative task commences.

Experiment 4

Experiments 2 and 3 have shown that the learning-dependent processes supporting distractor rejection can take place during the passive-viewing phase, a result that undermines the possibility that such filtering process can only be implemented strategically via top-down inhibitory signals applied to distractors for the successful completion of target discrimination. Rather, the results are more in agreement with the habituation of attention view, according to which Sokolovian-like mechanisms are automatically recruited to filter-out the irrelevant distracting event already during the passive viewing phase. However, the separate analysis of RTs in the distractor-present condition revealed that the distractor still exerted its detrimental effect on performance in the initial trials of the first active block. As discussed previously, one viable explanation is that habituation of capture, as established during passive viewing, needs some trials to become fully implemented in the context of an active task. However, an alternative habituation-related explanation exists, according to which the temporary increase in RTs could be attributable to a transient recovery of capture, namely an extinction of habituation, caused by the short block of practice trials performed just prior to the active blocks. One may argue, indeed, that habituation of capture was fully operational after passive viewing, but because during the 10 practice trials preceding the first active block the distractor was omitted, the capture response recovered. In support of this possibility, we have recently shown that, once the attentional capture response has habituated, the removal of the distractor for two consecutive blocks of trials (incidentally, please note that this is a lot more than 10 trials), in the same experimental context, caused a recovery of the habituated response (Turatto et al., 2018).

To test the "recovery of capture" hypothesis, in the present experiment the practice trials were performed before the passive-viewing phase, which was immediately followed by two blocks of active task. When distractor occurrence is not interrupted between the passive and the active phase, the initial lengthening of RTs should disappear if, in the previous experiments, it was caused by a recovery of the habituated capture response.

Method

Participants. Participants were 20 undergraduate students (12 female; mean age = 23.7 years) at the University of Trento and were recruited from the Department of Psychology and Cognitive Sciences for course credits or monetary compensation (8€). They had normal or corrected-to-normal vision, and were all naïve as to the purpose of the experiment.

Apparatus. The apparatus used was the same as in Experiment 1.

Stimuli and procedure. These were the same as in Experiment 2, with the two passive-viewing blocks immediately preceding two active blocks. Crucially, however, the block of practice (50 trials, in this case) was performed before the passive-viewing phase, that is, at the very start of the session. We slightly increased the number of practice trials from 10 (Experiments 1, 2, and 3) to 50 to allow participants to become fully proficient at the target discrimination task (i.e., to consolidate the S-R mapping process), because in the present experiment the practice phase took place 200 trials (i.e., the passive-viewing phase) before the beginning of the active task.

Results and Discussion

We first analyzed the participants' performance in the block of practice trials, subdivided in 10 bins of 5 trials each. As depicted in Figure 6 (bottom left panel), RTs rapidly decreased across subblocks, and then reached an asymptotic performance. This was confirmed by an ANOVA showing a significant main effect of the factor Subblock (10 levels), $F(9, 171) = 16.801$, $p = .001$, $^{2} = 1$, and by the fact that a negative exponential model significantly fitted the data ($y = 363.05 + 265.19e^{(-\text{subblock}/6.97)}$; $F(7) = 275$, $p < .001$, $R^2 = .98$).

As for the performance in the two active blocks, errors were 3% in the first active block and 2% in the second active block (the difference was not significant, $p = .515$), and were not analyzed further. The results on RTs, depicted in Figure 6 (top left panel), replicated those of Experiments 2 and 3. When the RT differences for correct responses were analyzed as a function of block, the ANOVA showed that the factor Block (two levels) was not significant, $F(1, 19) = .504$, $p = .486$, $^{2} = .104$; capture was significantly larger than zero in both the first ($p = .002$) and the second ($p = .004$) active block of trials. The amount of capture in

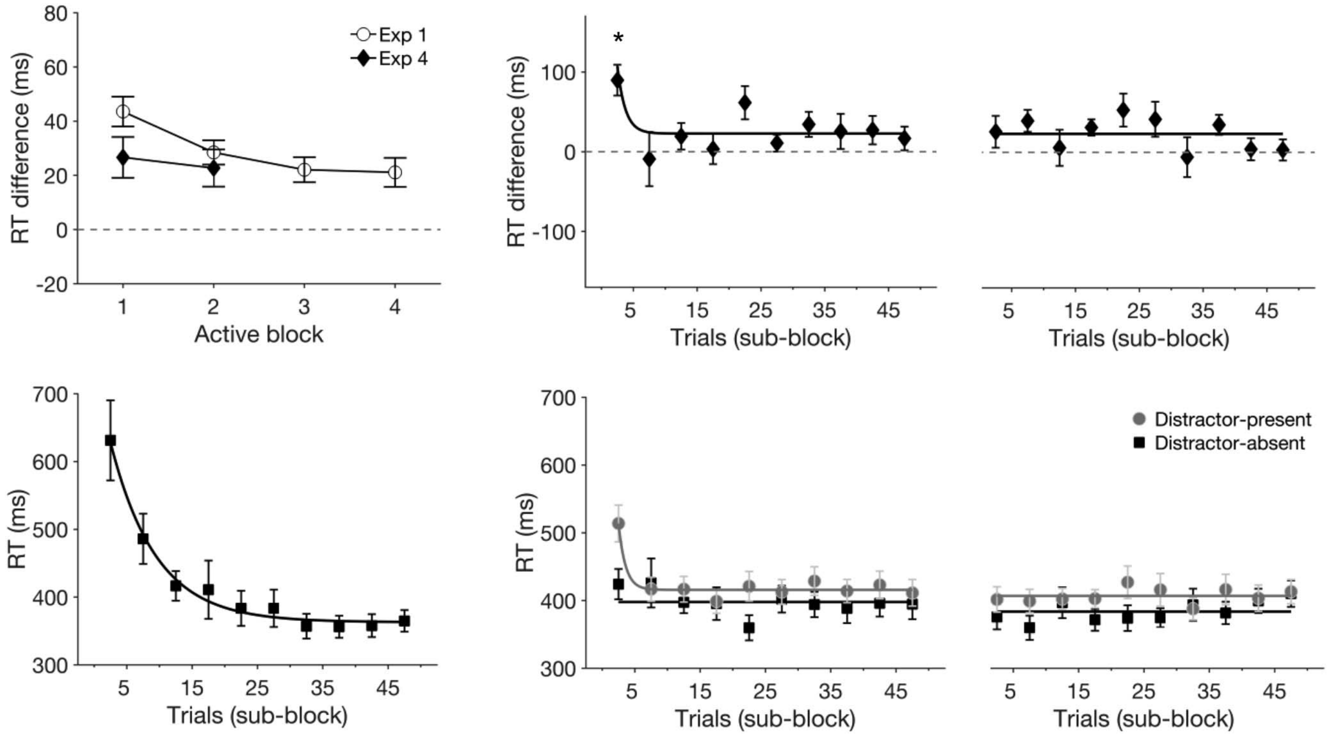

Figure 6. Top left panel: attentional capture as a function of active block in Experiments 1 and 4. Top middle and right panels: attentional capture as a function of subblock in the two active blocks. The asterisk indicates the subblock of trials in which capture was statistically significant ($p < .05$, Bonferroni corrected). Data points are plotted with their best-fitting model. Bottom panels: absolute Response times (RTs) in the distractor-present and distractor-absent conditions in the practice block (distractor-absent condition only) and the two active blocks. Data points are plotted with their best-fitting model. Bars represent ±1 *SEM*.

the first active block (M = 26 ms) was smaller than in the corresponding block 1 of Experiment 1 (M = 44 ms), although the difference only approached significance in this case, p = .072 (two tails), whereas no difference emerged between the two experiments in the second active block (p = .472).

The fine-grained temporal analysis of capture (see Figure 6, top middle and right panel) showed that in the first active block the factor Subblock was significant $F(9, 171) = 2.147$, $p = .028$, ^{2} = .872, as capture decreased significantly across subblocks. Pairwise comparisons showed that capture was reliably present only in the initial trials of the first active block (first subblock, $p < .05$, Bonferroni corrected), and then rapidly disappeared in the following part of the block. This RT pattern was well fitted by a negative exponential function ($y = 22.74 + 84.25e^{(-\text{subblock}/1.25)}$; $F(7) = 10.5$, $p = .01$, $R^2 = .56$). In the second active block, the factor Subblock was not significant, $F(9, 171) = 1.289$, $p = .246$, ^{2} = .617, and the RT pattern was better described by a flat function $F(7) = 1.48$, $p = .25$, $R^2 = .16$.

When RTs were analyzed separately for the distractor-present and distractor absent conditions across subblocks (see Figure 6, bottom middle and right panels), we observed that in the first active block RTs stayed constant across subblocks in the distractor-absent condition, whereas they showed a negatively accelerated function in the distractor-present condition. The two different patterns were confirmed by the fact that the negative exponential model was not significant for the distractor-absent condition, $F(7) = 3.42$, $p = .09$, $R^2 = .49$, whereas it nicely fitted the data in the distractor-present condition ($y = 415.82 + 97.93e^{(-\text{subblock}/1.08)}$; $F(7) = 53.2$, $p < .001$, $R^2 = .93$). On the contrary, in the second active block both RT functions were flat (all $p > .05$).

In the present experiment, practice trials, in which the distractor was omitted, were conducted before the passive-viewing phase, which was immediately followed by two blocks of active trials. Under these conditions, any recovery of the habituated capture response attributable to the omission of the distractor for some trials before the active block can be excluded. Therefore, the initial lengthening of RTs in the first subblock of trials in the distractor-present condition cannot be accounted for by a recovery of capture. This leaves open the possibility that, as discussed previously, this specific RT pattern reflects a short-lived impairment of performance attributable to any of the following factors: the recovery of the habituated (during passive viewing) attentional capture in the context of the active task, consistent with the observation that a change of the spatial context causes a temporary recovery of the previously habituated capture (Turatto et al., 2018); an object-based competition between the distractor and the target (Duncan, 1984; Treisman et al., 1983; van Boxtel & Koch, 2012), a conflict that was never experienced before by the participants during the passive-viewing phase, and that requires a few trials in the active block to be resolved; or finally, the necessity to relearn, or reoptimize, the S-R mapping (which was initially learned during the practice trials) within the context of a task with a distractor on 50% of the trials. As already noted, we find this possibility very unlikely, as it would predict a similar pattern in both the distractor-present and distractor-absent conditions.

Experiment 5

The key finding from Experiments 2, 3, and 4 is that the passive-viewing phase strongly attenuates the amount of interference (capture) exerted by the distractor on the discriminative task when participants are passively exposed to the irrelevant visual onset for a substantial number of trials (100). Two related results support this observation: first, the overall amount of capture at the block level is significantly larger in Experiment 1 as compared with Experiments 2, 3, and 4; second, the same difference emerges also when the cost is evaluated at the asymptotic performance level, namely when the initial slowing down of RTs in the distractor-present condition is excluded. In our view, these results provide strong evidence in favor of the habituation account. However, to provide more direct support to this interpretation, in the present experiment we directly tested the effect of the passive-viewing phase on attentional capture. If our interpretation is correct, we made the prediction that by removing the passive-viewing phase between the practice block and the active blocks, the amount of capture observed both overall, and at the asymptotic level, should increase with respect to that observed in Experiments 2, 3, and 4 (i.e., the distance between the asymptotic part of the distractor-present and absent functions should increase), as no habituation of capture can take place under these conditions.

Hence, the present experiment was identical to Experiment 4, but the two blocks of passive viewing were removed, and the active blocks immediately followed the block of practice. This experimental design had two purposes: on the one hand, in light of the significant reduction of capture observed after passive viewing in Experiments 2, 3, and 4, the current experiment allowed us to provide an important replication of Experiment 1, namely of the fact that without passive viewing the amount of capture (at least) in the first active block should increase substantially as compared with what found in Experiments 2, 3, and 4; second, because in Experiment 1 we were not successful in storing performance from the initial block of practice, here we had the opportunity to obtain data also from this initial phase, which could be useful for a better interpretation of the RT function in the distractor-absent condition in the first active block of trials.

Method

Participants. Participants were 20 undergraduate students (15 female; mean age = 23.1 years) at the University of Verona and were recruited from the Department of Neuroscience, Biomedicine and Movement Sciences for monetary compensation (8€). They had normal or corrected-to-normal vision, and were all naïve as to the purpose of the experiment.

Apparatus. The apparatus used was the same as in Experiment 1.

Stimuli and procedure. These were the same as in Experiment 4, with the exception that the two passive-viewing blocks were removed. As in Experiment 4, here too the practice block consisted of 50 trials (all distractor-absent trials). Participants were informed about the possible presence of the distractor just before commencing the two active blocks.

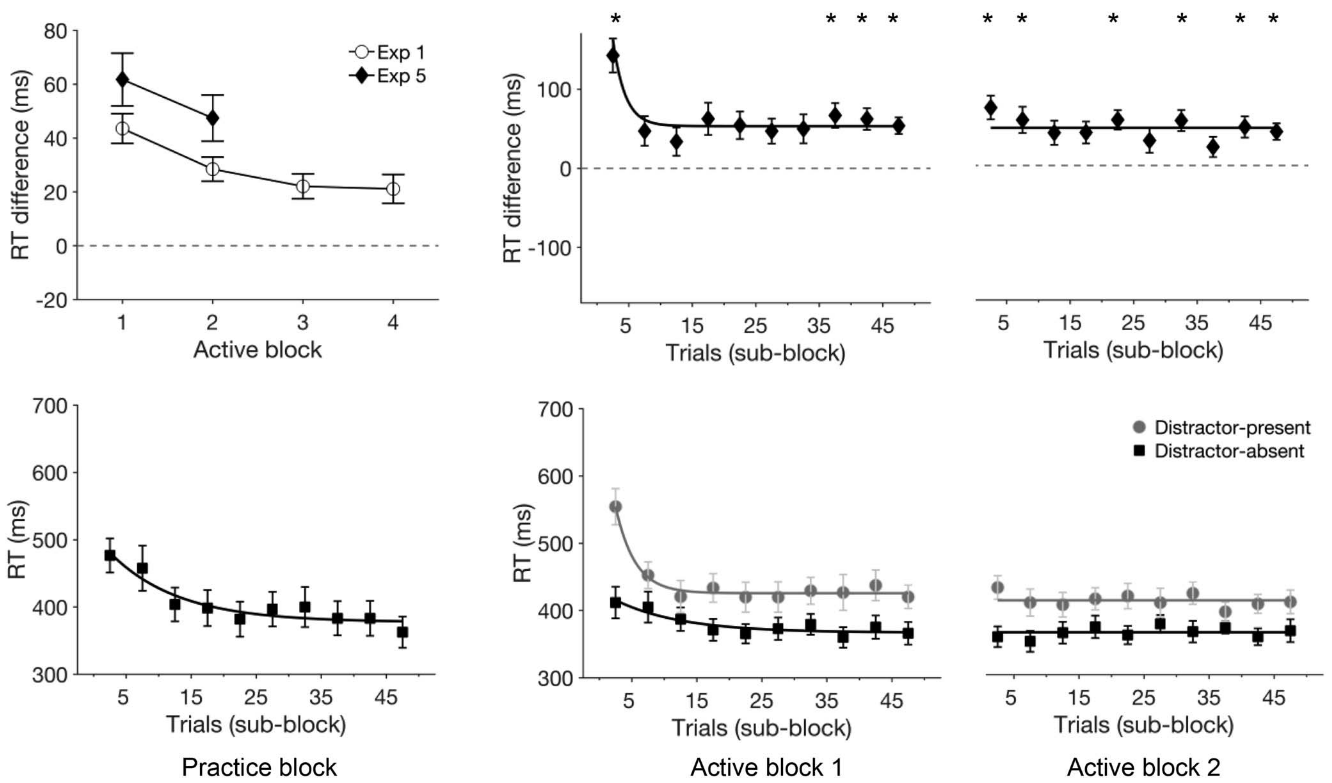

Figure 7. Top left panel: attentional capture as a function of active block in Experiments 1 and 5. Top middle and right panels: attentional capture as a function of subblock in the two active blocks. Asterisks indicate the subblocks of trials in which capture was statistically significant ($p < .05$, Bonferroni corrected). Data points are plotted with their best-fitting model. Bottom panels: absolute Response times (RTs) in the distractor-present and distractor-absent conditions in the practice block (distractor-absent condition only) and the two active blocks. Data points are plotted with their best-fitting model. Bars represent ±1 *SEM*.

Results and Discussion

The participants' performance in the block of practice trials, subdivided in 10 bins of 10 trials each, is depicted in Figure 7 (bottom left panel). As can be seen, RTs rapidly decreased across subblocks, and then reached an asymptotic performance level. This was confirmed by an ANOVA showing a significant main effect of the factor Subblock, $F(9, 171) = 6.452$, $p = .001$, $^2 = 1$, and by the fact that a negative exponential model significantly fitted the data ($y = 377.41 + 103.32e^{(-\text{subblock}/10.50)}$; $F(7) = 28.50$, $p < .001$, $R^2 = .89$).

As to the performance in the two active blocks, errors were 4% in the first active block, and 2% in the second active block (the difference was not significant, $p = .219$), and were not analyzed further. The results on RTs, depicted in Figure 7 (top left panel), diverged from those of Experiments 2, 3 and 4. When the RT differences for correct responses were analyzed as a function of block, the ANOVA showed that the factor Block (two levels) was significant, $F(1, 19) = 7.755$, $p = .012$, $^2 = .752$, as capture was significantly larger in the first than in the second active block of trials. However, in both blocks capture was larger than zero (all $p < .001$). The amount of capture in the first active block ($M = 62$ ms) was actually numerically larger than in the corresponding block of Experiment 1 ($M = 44$ ms), although the difference was not significant $p = .098$ (two tails); in addition, capture was significantly larger ($p = .046$, two tails) in the second block of the current experiment ($M = 47$ ms) as compared with Experiment 1 ($M = 28$ ms). Crucially, as expected because of the absence of the passive-viewing phase, the amount of capture in the first and second active blocks was larger than in the corresponding blocks of Experiments 2, 3, and 4 (all $p < .05$) in which participants were passively exposed to the distractor before commencing the active task.

The fine-grained temporal analysis of capture in the first active block showed that the factor Subblock (10 levels) was significant, $F(9, 171) = 4.022$, $p = .001$, $^2 = .995$, as capture decreased significantly across subblocks. However, pairwise comparison revealed that capture was reliably present across most of the subblocks: in the first, eighth, ninth, and 10th subblock ($p < .05$, Bonferroni corrected). Still, as in Experiments 2, 3, and 4, the RT pattern was fitted well by a negative exponential function ($y = 53.29 + 108.86e^{(-\text{subblock}/1.92)}$; $F(7) = 70.1$, $p < .001$, $R^2 = .89$). In the second active block, instead, the factor Subblock was not significant, $F(9, 171) = 1.56$, $p = .131$, $^2 = .720$. However, the lack of the passive-viewing phase made capture reliable also across most subblocks of the second active block, namely in the first, second, fifth, seventh, ninth, and 10th subblock ($p < .05$, Bonferroni corrected); finally, a negative exponential model did not fit the RT pattern in this block ($p > .05$, see Figure 7, top middle and right panels).

When RTs of the first active block were analyzed separately for the distractor-present and distractor absent conditions across subblocks (see Figure 7, bottom middle and right panels), we found that RTs followed a negatively accelerated function in both conditions (distractor present, $y = 425.76 + 128.84e^{(-\text{subblock}/2.96)}$; $F(7) = 128$, $p < .001$, $R^2 = .97$; distractor absent, $y = 367.28 + 48.25e^{(-\text{subblock}/10.13)}$; $F(7) = 17.7$, $p = .001$, $R^2 = .83$). By contrast, in the second active block both RT functions were flat (all $p > .05$).

As predicted, the amount of capture in the first and second active blocks was larger than in previous Experiments 2, 3, and 4, which is consistent with the idea that in these experiments distractor filtering mechanisms were already implemented during passive viewing. Hence, when the passive exposure phase was removed, as in the present experiment, the distractor caused a substantial cost in the discriminative task, a cost that persisted through the second active block. More generally, the present findings represent an important replication of the basic observation from Experiment 1 that the cost in performance attributable to the peripheral onset distractor diminishes slowly over time when the active task condition is not preceded by a phase of passive viewing during which the onset distractor is experienced repeatedly by the participants.

Furthermore, the results from the distractor-present condition are also relevant for another important reason. So far we have interpreted the initial lengthening of RTs in this condition as a cost caused by the need to disregard the distractor, already seen during the passive viewing phase, in the context of an active task. Here we found that the same negatively accelerated function is evident also when the passive-viewing phase was omitted, which suggests that this RT pattern may have little to do with the learning process taking place during the passive exposure to the distractor. Rather, because this RT pattern emerges regardless of any experience with the distractor before the active task (Experiment 5), and that it is not a result of the fact that the target and the distractor are both onset elements (Experiment 3), or to the spontaneous recovery of the habituated capture (Experiment 4), it seems plausible that such transient cost is caused by a nonspatial conflict between the distractor and the target (Duncan, 1984; Treisman et al., 1983; van Boxtel & Koch, 2012). As an alternative explanation, one might conjecture that the S-R mapping process must again be optimized in the presence of the distractor—an option that we find less likely for reasons that we have already discussed. One way or another, it appears that participants need to optimize task performance anew in the presence of the extraneous irrelevant onset.

At any rate, in our view, the large initial RT difference between the distractor-present and distractor-absent condition, in turn caused by the disproportionally long RTs in the distractor-present condition, is unlikely to reflect an involuntary shift of spatial attention (capture), since we have seen that this takes a lot longer to habituate (e.g., the top left panel in Figure 2). Instead, we believe that the habituation of the attentional capture response is better indexed by the degree of separation between the distractor-present and the distractor-absent condition at the asymptotic performance level. Finally, one should note that in the first active block of the present experiment RTs showed an initial slowing down also in the distractor-absent condition, though much less pronounced than in the distractor-present condition. One plausible and parsimonious explanation is that, unlike in previous experiments, at the end of the practice block participants had not yet reached an optimal level of proficiency in two related processes, namely selection of the task-relevant target features and the ensuing S-R mapping, thus leaving room for further improvement during the first trials of the active block.

Experiment 6

The results from the previous set of experiments clearly indicate that distractor filtering to reject the irrelevant peripheral visual onset was already implemented during the passive-viewing phase, even in the absence of any discriminative task. However, because during passive viewing participants were instructed to maintain central fixation, which was monitored in each of the previous experiments, one may argue that participants were actively engaged in trying to counteract any oculomotor capture triggered by the peripheral distractor (Theeuwes, Kramer, Hahn, & Irwin, 1998). In other words, the suppression mechanisms used to filter out the distractor could have been under goal-directed control, at least to some extent, to maintain attention and the eyes on the fixation cross. Because so far we have argued that distractor filtering was likely achieved via habituation, implying that it was implemented in a more automatic fashion and regardless of the current task, to exclude a major contribution of top-down goal-directed components necessary to maintain central fixation, in the present experiment we left participants free to move their eyes during the passive-viewing phase. Should we replicate the previous findings of reduced capture after the passive viewing phase even under conditions of unconstrained eye movements, the strategic-filtering hypothesis would be very unlikely to account for our results.

Method

Participants. Participants were 20 undergraduate students (16 female; mean age = 22.6 years) at the University of Trento and were recruited from the Department of Psychology and Cognitive Sciences for course credits or monetary compensation (8€). They had normal or corrected-to-normal vision, and were all naïve as to the purpose of the experiment.

Apparatus. The apparatus used was the same as in Experiment 1.

Stimuli and procedure. These were the same as in Experiment 2, with the following exception: participants were required to maintain central fixation only during the first 200 ms after trial onset. Then, they were free to move their eyes during the remainder of the trial.

Results and Discussion

Errors were 2% in both the first and the second active block and were not analyzed further. The results on RTs, depicted in Figure 8 (top left panel), replicated those of Experiments 2 and 3. When the RT differences for correct responses were analyzed as a function of block, the ANOVA showed that the factor Block (two levels) was not significant, $F(1, 19) = 1.584$, $p = .223$, $^2 = .223$; however, the difference was larger than zero in both the first ($M =$

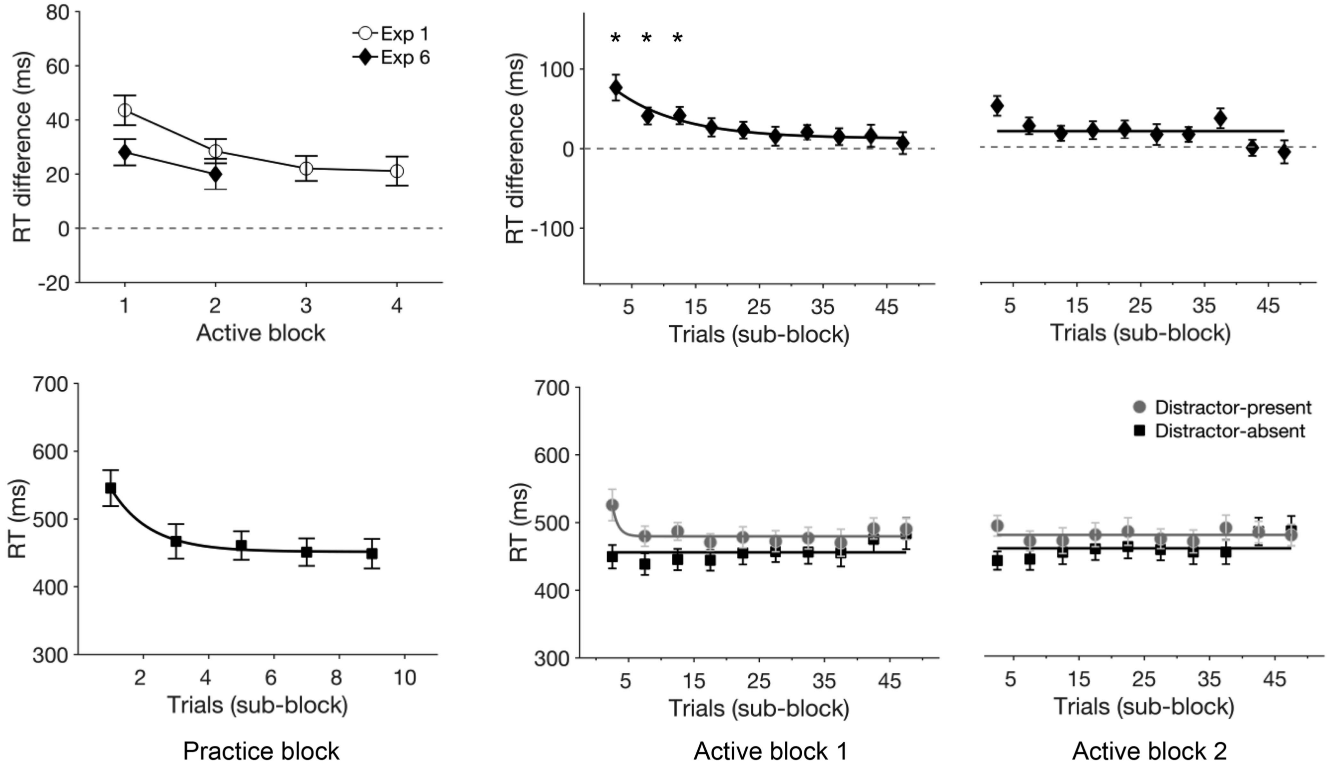

Figure 8. Top left panel: attentional capture as a function of active block in Experiments 1 and 6. Top middle and right panels: attentional capture as a function of subblock in the two active blocks. Asterisks indicate the subblocks of trials in which capture was statistically significant ($p < .05$, Bonferroni corrected). Data points are plotted with their best-fitting model. Bottom panels: absolute Response times (RTs) in the distractor-present and distractor-absent conditions in the practice block (distractor-absent condition only) and the two active blocks. Data points are plotted with their best-fitting model. Bars represent ±1 *SEM*.

28 ms; $p < .001$) and the second ($M = 20$; $p = .002$) active block of trials.

The fine-grained temporal analysis of capture showed that in the first active block the factor Subblock (10 levels) was significant, $F(9, 171) = 3.058$, $p = .002$, $^2 = .970$. Pairwise comparisons showed that capture was reliable only in the first 3 subblocks ($p <$ .05, Bonferroni corrected), and then disappeared in the following part of the block (see Figure 8, top middle and right panels). Accordingly, this RT pattern was well fitted by a negative exponential function ($y = 12.60 + 60.84e^{(-\text{subblock}/10.28)}$; $F(7) = 59.8$, $p < .001$, $R^2 = .92$). In the second active block the factor Subblock was also significant, $F(9, 171) = 2.470$, $p = .011$, $^2 = .921$, and pairwise comparisons showed that capture was reliable only in the 1st subblock ($p > .05$, Bonferroni corrected). However, this RT pattern was better described by a flat function, rather than by a negative exponential model, $F(7) = 3.7$, $p = .08$, $R^2 = .51$.

When RTs were analyzed separately for the distractor-present and distractor absent conditions across subblocks (see Figure 8, bottom panels), we found that in the first active block RTs stayed constant across subblocks in the distractor-absent condition, whereas they showed a negatively accelerated function in the distractor-present condition. Accordingly, the negative exponential model was not significant for the distractor-absent condition, $F(7) = .22$, $p = .65$, $R^2 = .02$, whereas it nicely fitted the data in the distractor-present condition ($y = 479.60 + 46.35e^{(-\text{subblock}/0.87)}$; $F(7) = 12.7$, $p = .004$, $R^2 = .78$). On the contrary, in the second active block both RT functions were flat ($p > .05$).

A negative exponential model (Figure 8, bottom left panel) provided a good fit for the practice trials of Experiment 6 ($y = 451.63 + 93.71e^{(-\text{subblock}/1.19)}$; $F(2) = 131$, $p = .007$, $R^2 = .99$). The RTs decay across subblocks in the practice trials was confirmed by an ANOVA for repeated measures with Subblock (five levels) as factor, which was significant, $F(4, 72) = 7.202$, $p <$ .001, $^2 = .99$.

Importantly, in the present experiment, when participants were free to move their eyes, the rate of saccades directed toward the distractor in the passive viewing phase was much higher (34%) than that in the same phase of Experiments 2 (1%), 3 (6%), and 4 (2%), when participants were instructed to maintain central fixation. This pattern of results confirms that, when fixation was not required, participants made a consistent number of saccades toward the distractor, which in turn implies that they were not making an effort to resist (oculomotor) capture by the peripheral onset stimulus. However, in spite of this, the results were highly similar to those of previous experiments in which eye movements were not allowed, thus confirming a strong reduction of capture as a result of the passive-viewing phase. Because in the present experiment participants were free to move their eyes during the passive viewing phase, this undermines the possibility that the attenuation of attentional capture, as found in this and previous experiments, was achieved via a top-down goal-directed mechanism, that purposefully suppressed the distractor to avoid reflexive saccades toward the irrelevant visual onset. Rather, the results are consistent with a key role of habituation mechanisms, which attenuate the exogenous attentional capture independently of any strategic voluntary control.

Experiment 7

In all the previous experiments, regardless of the manipulation that we applied, we found that RTs in the distractor-present condition followed a rapid negatively accelerated function, which then leveled off in a few trials at a lower asymptotic level. In other words, the passive-viewing phase does not appear to be sufficient for eliminating an initial slowing down of RTs caused by the presence of the distractor within the context of an active task, a cost that we have argued may be attributable to a form of nonspatial conflict between the target and the distractor. However, because of the strong similarity of this RT function with that observed in the practice trials (distractor-absent condition), one might also hypothesize that the distractor, when initially presented in the context of the discriminative task, directly hampered the previously learned S-R mapping, which therefore needs to be relearned within the new context.

While S-R mapping optimization for a given task could be specific for the distractor-present and distractor-absent condition, one may ask whether, conversely, the learning mechanism leading to habituation of attentional capture is specific for the discriminative task being performed while exposed to the given distractor. In this regard, the habituation account and the strategic top-down filtering account might make opposite predictions. On the one hand, if we are correct in claiming that habituation is automatically triggered by the occurrence of the distractor, regardless of the presence of an active task, we expect habituation for a given distractor to be task independent, namely the reduced attentional capture observed during one task should transfer to a different task. On the other hand, if distractor filtering is dictated by the need to protect target processing from interference, distractor rejection might be yoked to the target with which the distractor is interfering, thus making habituation of attentional capture task specific. Whether or not these conjectures are correct, with the following experiment we aimed at testing whether habituation of attentional capture generalizes across different tasks.

To evaluate these alternative possibilities, in this final experiment participants were presented with the same display across five different blocks of trials. The display consisted of a central stimulus, serving as the target, and a peripheral distractor appearing on 50% of the trials. In the initial four blocks participants were asked, for example, to discriminate the target shape (square vs. diamond), whereas in the last block the task was changed, and participants had to discriminate the target color (red vs. green). The distractor remained always the same. We expected the detrimental effect of the distractor to diminish with practice across the four initial blocks; crucially, on the fifth block the capture response could either remain habituated or recover as a result of a change in task context.

In addition, in the present experiment, we slightly modified the paradigm by presenting the target at fixation instead that within one of the four peripheral placeholders. Although the logic of the paradigm is the same, namely to measure habituation of capture from a peripheral sudden onset, by placing the target at fixation we aimed to show that our results (i.e., habituation) are robust, and that they generalize across different retinal locations and tasks.

Method

Participants. Participants were 18 undergraduate students (10 female; mean age = 20.25 years) at the University of Trento and were recruited from the Department of Psychology and Cognitive Sciences for course credits or monetary compensation (8€). They had normal or corrected-to-normal vision, and were all naïve as to the purpose of the experiment.

Apparatus. The apparatus used was the same as in Experiment 1.

Stimuli and procedure. The experiment consisted of five blocks of 80 trials each. Each trial started with the presentation of a gray central fixation point (23.8 cd/m^2) with a radius of 0.3°. After a jittered interval of 1000 –1500 ms the target stimulus appeared in a central position around the fixation point. The target stimulus (1.2° of visual angle) could be a square or a diamond, and it could appear in red (18 cd/m^2, CIE: $x = .643$, $y = .345$) or green (18 cd/m^2, CIE: $x = .268$, $y = .548$). In the distractor present condition (50% of the trials), the target was preceded (100-ms SOA) by the appearance of a peripheral onset distractor, consisting in a high-luminance white circle (71 cd/m^2, 2° in diameter) that was presented for 100 ms in one of four possible locations (with an eccentricity of 7°). The position of the distractor was randomly chosen on each trial. The display with the fixation point and the target remained onscreen until participants responded or until 1500 ms were elapsed from the target onset. The next trial began after an interval of 1000 ms, during which the screen was blank. Before the beginning of the first active block participants performed a short block of 10 practice trials without the distractor. Task instructions and procedure were shown onscreen before the practice block.

Results and Discussion

Errors were less than 1% in each block and were not analyzed further. An ANOVA on RTs with Block as the only factor resulted in a significant effect, $F(4, 68) = 2.645$, $p < .041$, $= .710$, attesting to a decrement of capture across blocks. Crucially, as inspection of Figure 9 reveals, the task change that occurred in block 5 did not cause a recovery of capture as compared with block 4 ($p = .295$, two tails).

In support of this conclusion, we also conducted a fine-grained temporal analysis of attentional capture, as in the previous experiments. The results (see Figure 9, middle panels) showed that in the first block the factor Subblock (eight levels) was significant, $F(7, 119) = 5.20$, $p < .001$, $^2 = .997$, with capture decreasing significantly across subblocks. Pairwise comparisons showed that capture was reliably present only in the initial trials of the first block (1st and 2nd subblocks, all $p < .05$, Bonferroni corrected), and then rapidly disappeared in the following part of the block. Accordingly, this RT pattern was well fitted by a negative expo-

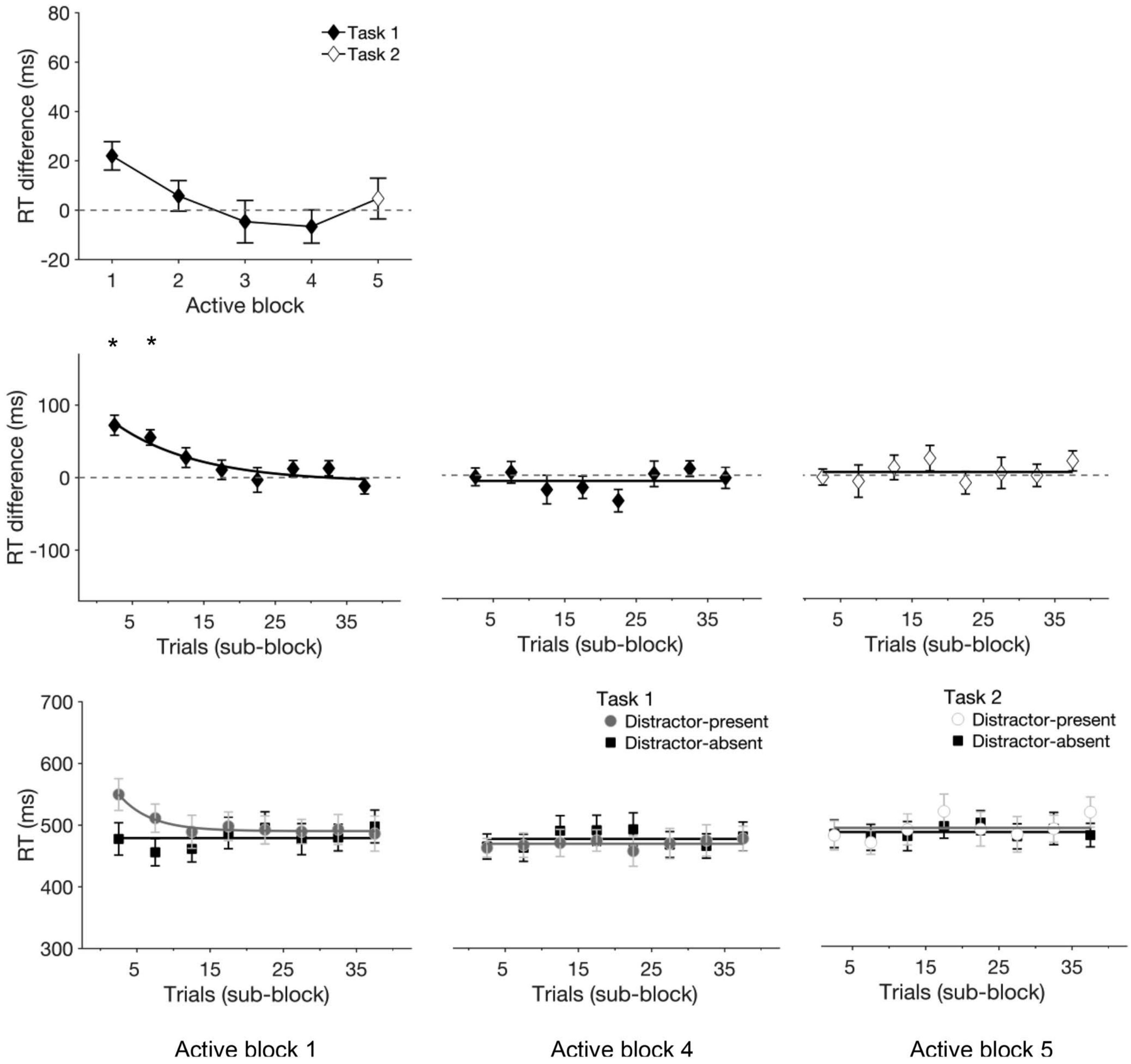

Figure 9. Top panel: attentional capture as a function of active block in Experiment 7. Middle panels: attentional capture in block 1, 4 and 5, in which Response times (RTs) were divided in 10 subblocks of 10 trials each. Asterisks indicate the subblocks of trials in which capture was statistically significant ($p < .05$, Bonferroni corrected). Data points are plotted with their best-fitting model. Bottom panels: absolute RTs in the distractor-present and distractor-absent conditions of block 1, 4 and 5, as a function of subblock. Data points are plotted with their best-fitting model. Bars represent ±1 *SEM.*

nential function ($y = -6.19 + 81.52e^{(-\text{subblock}/11.60)}$; $F(5) = 22.10$, $p = .003$, $R^2 = .89$). In the following blocks, instead, the factor Subblock was not significant (all ps $> .05$), and the RT pattern in each block was better described by a flat function.

As before, data were also analyzed by considering absolute RTs in the distractor-present and distractor-absent conditions separately across subblocks (see Figure 9, bottom panels). In particular, in the first block average RTs stayed roughly constant across subblocks in the distractor-absent condition, whereas they showed a negatively accelerated function in the distractor-present condition. The two different patterns were confirmed by the fact that the negative exponential model was not significant for the distractor-absent condition, $F(5) = 1.61$, $p = .289$, $R^2 = .39$, whereas it nicely fitted the data in the distractor-present condition ($y = 490.33 + 59.55e^{(-\text{subblock}/4.29)}$; $F(5) = 64.8$, $p < .001$, $R^2 = .96$). On the contrary, in the subsequent blocks both RT functions were flat

($p > .05$). In addition, as depicted in Figure 9 (top right panel), a negative exponential model provided a good fit for data from the practice trials ($y = 471.41 + 55.30e^{(-\text{subblock}/1.85)}$; $F(2) = 15.4$, $p = .06$, $R^2 = .94$).

The findings emerged from the present experiment are in line with the habituation account, showing that the mechanisms supporting the reduction of capture as a result of experience are based on a distractor representation that is independent from the discriminative task during which filtering takes place.

General Discussion

The attention system is inherently responsive to salient stimuli, which makes distraction virtually inevitable. From the point of view of the organism's survival, distraction is, in the end, a cost that is worth paying to be always ready to inspect, and eventually react to, potentially relevant (e.g., aversive or appetitive) events, like those often signaled by sudden visual onsets. However, once a distracting stimulus has turned out to be innocuous and irrelevant, the cognitive system must be capable of ignoring further occurrences of the same stimulus to prevent repetitive, unwanted distraction, and consequently the continuous wasting of valuable limited-processing resources. Therefore, the characterization of the specific cognitive and neural mechanisms for distractor filtering has recently become a central topic in the study of attention.

Different strategic top-down mechanisms for distractor filtering have been proposed (Gaspelin & Luck, 2018; Geng, 2014), hinging on the idea that top-down inhibitory signals are applied to the distractors for the successful completion of goal-directed behavior. This strategic-suppression view explicitly assumes that distractor filtering is under top-down control, meaning that suppression of distractors would be purposefully implemented to restrict attentional processing to the target item. Suppression would either result from a direct inhibitory signal deliberately applied to the distractors (Awh et al., 2010; Geyer et al., 2008), or the consequence of the adoption of a precise attentional set (feature-search mode) tuned to the specific target features (Bacon & Egeth, 1994). Other studies have prevalently emphasized the role of learning processes rather than of explicit knowledge or strategy, and have shown that filtering can also take place because of experience-dependent attentional tuning of distractor rejection (Ferrante et al., 2018; Leber & Egeth, 2006a; Leber et al., 2016; Vatterott & Vecera, 2012; Wang & Theeuwes, 2018). However, regardless of whether distraction is counteracted proactively, reactively, or as a consequence of a (statistical) learning process, the widely shared idea is that distractor rejection is dictated by the need to shelter target processing from interference (Awh et al., 2010; Dixon et al., 2009; Geng, 2014; Geyer et al., 2008; Marini et al., 2013, 2016).

Alternatively, the ability of the cognitive system to progressively ignore a recurrent distractor can also be interpreted in light of the more general phenomenon of habituation (Thompson, 2009; Thompson & Spencer, 1966). This basic form of behavioral plasticity is ubiquitously present in the animal kingdom (Harris, 1943), and reflects the ability of the organism to adapt its behavior on the basis of past experience. However, it is important to stress the fact that habituation reflects a response reduction that is not accounted for by sensory (perceptual adaptation) or motor fatigue, namely, habituation is a central process that relies on the ability of the nervous system to predict the incoming information on the basis of the history of stimulation (Ramaswami, 2014; Sokolov, 1963). Specifically, with practice, the organism learns to reduce its responsiveness to irrelevant and innocuous stimuli when these are repeatedly encountered. Although at the cellular level the synaptic mechanisms of habituation have long been studied (Carew & Kandel, 1973; Castellucci, Carew, & Kandel, 1978; Ezzeddine & Glanzman, 2003), theories of habituation have also been proposed at the behavioral level (Groves & Thompson, 1970; Konorski, 1967; Sokolov, 1963; Wagner, 1979). Among the most influential, Sokolov's *stimulus-model comparator* theory is specifically concerned with habituation of the OR, thus providing a mechanism for habituation of covert spatial attentional capture (Neo & Chua, 2006; Pascucci & Turatto, 2015; Turatto & Pascucci, 2016). Accordingly, previous studies have proposed that habituation of attention, based on a Sokolovian-like model, would reflect the operation of a filtering mechanism for those nontask relevant stimuli that occur in a repetitive fashion (Cowan, 1988; Elliott & Cowan, 2001; Kraut & Smothergill, 1978; Waters et al., 1977). More recent studies have argued for a close link between habituation and attention (e.g., Dukewich, 2009), thus providing further support to this view (Ben-Shakhar, Gati, Ben-Bassat, & Sniper, 2000; Codispoti, De Cesarei, Biondi, & Ferrari, 2016; Forster & Lavie, 2008; Neo & Chua, 2006; Pascucci & Turatto, 2015; Waters et al., 1977), and have also shown that habituation of attentional capture by visual onsets has both short-term and long-term components (Turatto & Pascucci, 2016), and that it can be context specific (Turatto et al., 2018).

The current study provides insightful information as to the plausibility of the distractor filtering mechanisms postulated by the strategic-suppression view as opposed to those underlying the habituation view. More specifically, with the experiments reported here we wished to contrast directly predictions from the two accounts. To summarize the main findings, we showed that during the course of an active task, attentional capture exerted by a peripheral sudden onset distractor diminished steadily over the course of the experiment (Experiments 1 and 5). Next, we showed that, similar to what found during an active task, repeated passive exposure (from tens to hundreds of trials) to a peripheral onset strongly reduced its ability to capture attention when later presented during a subsequent discriminative task (Experiments 2 and 3). Second, the reduced distraction promoted by the passive-viewing phase appears to be largely independent from an inhibitory top-down control exerted to maintain central fixation while exposed to the peripheral distractor (Experiment 6). Third, although passive viewing had a profound beneficial effect on the ability to resist visual distraction, a residual performance cost was still briefly present (for a few trials) when participants experienced the distractor in the context of a new discriminative task (Experiments 2– 6). Importantly, we showed that this transient cost could not be accounted for in terms of recovery of capture attributable to extinction of habituation (Experiment 4). Finally, we showed that habituation of capture by a peripheral onset distractor was preserved across different task contexts (Experiment 7).

Hence, although there is no doubt that the ultimate goal of avoiding distraction is that of keeping attention focused on the relevant task at hand, we showed that to exclude unwanted information, here consisting of a sudden peripheral visual onset that was encountered on 50% of trials, the cognitive system can capitalize on a mechanism that starts to operate even when there is neither a target to be processed, nor an advance knowledge of the target that will be presented in the subsequent phase (and of the task to be performed next). Rather, our results indicate the existence of a learning-dependent mechanism that is activated by virtue of the mere exposure to a recurring salient onset, even in the absence of any attentional set for the target features. During the passive-viewing phase, despite the lack of any target processing, the cognitive system appears to be capable of learning the characteristics of the irrelevant salient stimulation, and to reduce the responsiveness of the attention system to it, thus significantly decreasing the impact of the distractor upon start of the active task.

So far, to highlight the beneficial effects of the passive-viewing phase in reducing the amount of capture we have mainly considered the fact that the distractor cost in the first two active blocks of Experiments 2, 3, 4, and 6 (with passive viewing) was significantly lower as compared with the cost in the corresponding blocks of Experiments 1 and 5 (no passive viewing). However, the beneficial effects of passive viewing appear to be even more remarkable if one considers that the degree of attentional capture after this phase is comparable to that observed after two blocks of active trials in those experiments where there was no passive-viewing phase. Indeed, RTs in the 1st and 2nd active blocks of Experiments 2, 3, 4, and 6 were statistically indistinguishable from those of the 3rd and 4th active blocks of Experiment 1 (all $p > .3$). Put differently, the evidence suggests that the amount of learning associated with distractor rejection that is achieved in two blocks of passive viewing, during which the distractor did not interfere with any target-related processing, is equivalent to that obtained after two blocks of active task, when one might assume that the distractor is actively filtered to shield target processing from interference.

In addition, because the passive viewing benefits on performance were observed also when participants were free to move their eyes during this phase, it seems safe to conclude that habituation of attentional capture was not attributable to top-down suppression mechanisms implemented to filter the distractor to maintain central fixation and avoid reflexive saccades toward the peripheral onset.

The collected evidence is fully consistent with the habituation view, whereby the filtering mechanism would operate in an automatic fashion on the basis of the sensory input, which is then confronted with an internal model built through past experience (Sokolov, 1963). As already pointed out in the Introduction, by claiming that habituation mechanisms operate automatically (also see, Steiner & Barry, 2014) we do not mean that their functioning does not demand cognitive resources. In fact, as previous studies have shown, habituation rate correlates with WM capacity (Sörqvist, 2010; Sörqvist et al., 2012; Sörqvist & Rönnberg, 2014), which indicates that central cognitive resources may be used for the implementation of the habituation process. What we suggest, instead, is that the implementation of this type of filtering mechanism is not under strategic or voluntarily control, but rather that through habituation mechanisms the cognitive system automatically and constantly monitors the correspondence between the predictive model of the external world and the incoming signals. Similarly to what was originally proposed by Sokolov (1963), and by more recent theories on adaptive filtering and dynamic predictive coding (Huang & Rao, 2011; Ramaswami, 2014), mechanisms based on a neural model of the history of stimulation would emphasize novelty by reducing the (attentional) response evoked by recurrent irrelevant stimuli, thus explaining habituation of attentional capture.

Overall, the present pattern of results is in accordance with evidence from a related line of research on the habituation of attentional capture triggered by irrelevant auditory distractors during a visual memory task. Research on this topic has revealed that the detrimental effect of an irrelevant sound on the visual memory performance diminishes as exposure to the distractor repeats, thus revealing a form of habituation of cross-modal attentional capture (Bell et al., 2012; Röer et al., 2014, 2015; Sörqvist, 2010). Importantly, though, we underscore that, to the best of our knowledge, this is the first report and thorough characterization of habituation-like reduction of attentional capture attributable to the passive exposure to a distractor within the visual modality. In turn, this is not a trivial advancement of our understanding of attention in general, and of the mechanisms supporting distractor filtering in particular, especially in view of the rapidly increasing literature exploring these mechanisms in the visual modality (Gaspelin & Luck, 2018; Geng, 2014)—a literature that so far appears to have almost completely neglected the possibility that distractor rejection can be supported, at least under certain circumstances, by the sort of habituation-like mechanisms that we have explored in the present study (but see notable exceptions, e.g., Gati & Ben-Shakhar, 1990; Neo & Chua, 2006; Pascucci & Turatto, 2015; Turatto et al., 2018; Turatto & Pascucci, 2016). However, as already said, habituation-related mechanisms based on the history of stimulation are not the only means by which the cognitive system can counteract distraction. Indeed, there are solid indications from both unimodal and cross-modal attention studies attesting to the role of top-down control in attentional capture, for example by showing that increasing the cognitive/attentional load of the main task reduces the distracting impact of a peripheral distractor (Lavie, 2010; Sörqvist, Dahlström, Karlsson, & Rönnberg, 2016).

Central to our argument that during passive viewing the cognitive system can learn to disregard the peripheral visual onset when repeatedly encountered is the fact that the amount of attentional capture induced by the distractor, as indexed by the RT difference at the asymptotic level, is reduced by the passive exposure phase. In support of this claim, which is key to our study, we conducted a further analysis showing that, as compared with when no passive viewing was allowed (Experiments 1 and 5, pooled together and leading to an overall sample of 44 participants), the attentional capture effect in the first active block at asymptotic level (i.e., when the RT function is flat) was significantly reduced ($p < .001$, two-tailed independent samples t test) in all cases where participants were previously passively exposed to the distractor, regardless of any discriminative task (Experiments 2, 3, 4, and 6, pooled together and leading to an overall sample of 88 participants; see Figure 10).

This result parallels observations from previous studies in which, using a similar preexposure manipulation, habituation of cross-modal attentional capture has been reported. For example, Elliott and Cowan (2001; also see, Bell et al., 2012; Waters et al., 1977) had their participants name the color of a centrally presented visual stimulus, while they were exposed to acoustic distractors consisting of color words, noncolor words or simple tones. With practice participants learned to reduce the interference caused by the acoustic distractors; crucially, however, comparable effects

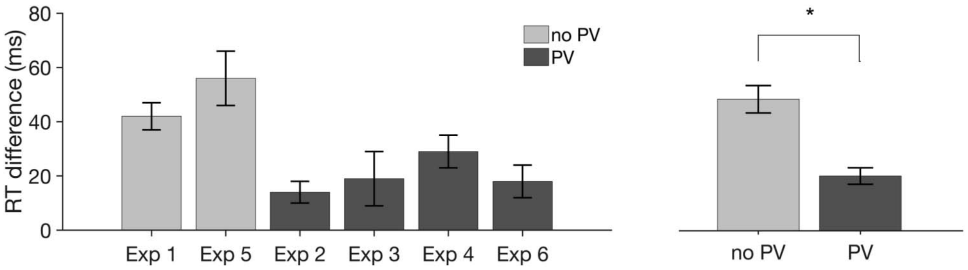

Figure 10. Left panel: attentional capture in the first active block at asymptotic level (i.e., from subblock 5 to 10), as a function of experiments. The amount of capture was larger in Experiments 1 and 5, in which no passive viewing took place, than in the remaining experiments, in which participants were passively exposed to the distractor for two blocks of trials. Right panel: average attentional capture in the first active block at asymptotic level, in experiments with (PV) or without (no PV) passive viewing. The asterisk indicates that the difference was significant ($p < .001$, two tails independent samples t test). Bars represent ±1 *SEM*.

were obtained also when participants were passively exposed to the distractors before starting the color-naming task, thus suggesting that during the preexposure phase a neural model of the irrelevant acoustic stimuli was automatically formed and later used to attenuate the processing of the distractors when the task began, as predicted by the habituation view (Sokolov, 1963).

One may wonder whether the reduced sensitivity to the visual distractor that we documented as a result of passive exposure can be explained by perceptual adaptation rather than by habituation (mechanisms), given that they both imply a response reduction at some level of the neural cascade. There are several reasons to believe that our results are an instance of habituation of capture, rather than of perceptual adaptation. To begin with, visual adaptation is mainly observed when the visual system is confronted with the same stimulation for second or minutes (Carandini, 2000). Under these conditions, when a test stimulus is presented following extended exposure to an adapting stimulus, perceptual appearance of the former is affected by the latter. The perceptual change is assumed to reflect calibration mechanisms that adapt the visual system, from the retina to the cortex, to the dominant attributes of the adapting stimulus (e.g., light intensity, contrast, orientation, motion direction, etc.; Carandini, 2000). Adaptation emerges because a prolonged stimulation induces a sort of neural "fatigue" in those neurons that most strongly respond to the main characteristics of the adapting stimulus, such that after a while the same neurons respond less vigorously than before the adapting stimulation, and, as a consequence, perception is biased away from the adapting stimulus (e.g., the tilt aftereffect, or the motion aftereffect; Thompson & Burr, 2009; Webster, 2012). Given that in our paradigm the distractor appeared for only 100 ms, and on 50% of the trials (i.e., with an average inter trial interval of approximately 4000 ms), and that it also randomly changed its spatial position on a trial-by-trial basis, it seems very unlikely that stimulus adaptation may have contributed to our results. In addition, our previous studies showed that habituation of attentional capture analogous to the one reported here can persist unchanged for days after training (Turatto et al., 2018; Turatto & Pascucci, 2016), which reasonably rules out a role of visual adaptation in our paradigm. By contrast, the present findings are in agreement with the idea that habituation is a central process relying on a neural model generating a prediction of the upcoming events on the basis of past stimulation (Ramaswami, 2014; Sokolov, 1963). The predictive nature of the neural model underlying habituation of capture, which would help the cognitive system to allocate attention only to salient and unexpected stimuli, is confirmed by studies showing that expectancy violation, with respect to an irrelevant auditory sequence, is the main factor that triggers the recovery of the habituated capture response to an auditory distractor (Vachon, Hughes, & Jones, 2012).

In sum, the standard analysis of attentional capture conducted on RTs at the block level provided a consistent picture by showing that during the two initial blocks of passive viewing a (latent) learning phenomenon took place, which strongly reduced the amount of distraction caused by the peripheral onset upon start of the discriminative task (see Experiments 2, 3, 4, and 6). Therefore, although top-down suppression strategies applied to distractors can certainly be a viable solution to facilitate the analysis of behaviorally relevant stimuli (Gaspelin, Leonard, & Luck, 2015; Geng, 2014), here we showed that the our cognitive system can learn to exclude unwanted, irrelevant information by means of a habituation mechanism, not dictated by the need to shield target processing from interference. Furthermore, it seems reasonable to assume that a habituation-like mechanism can also account, at least to some extent, for the results of previous studies reporting a reduction of attentional capture as the exposure to the same distractor continues across several trials (e.g., Kelley & Yantis, 2009; Vatterott & Vecera, 2012; Vecera, Cosman, Vatterott, & Roper, 2014).

In addition to this main finding, the subblock analysis, especially in the first active block, wherein distractor-present and distractor-absent trials were considered separately, was helpful in clarifying the cognitive processes determining task performance. As for the distractor-absent condition, target discrimination performance reached an asymptotic level within a few trials during the practice block, and then the RT function remained flat during the following active blocks. The only exception to this robust pattern emerged in Experiment 1, in which, at the beginning of block 1, the RT function was not flat, and it took a few trials to reach the asymptote, thus paralleling the RT function of the distractor-present condition. The negative exponential decay function describing RTs in the practice block is likely to represent a rapidly occurring process of optimization of task performance, including efficient selection of the task-relevant feature of the target stimulus, and optimal S-R mapping, or in general familiarization with the discriminative task. Once this fast-occurring task learning process was complete, performance remained fairly constant within the same block of trials, and for the most part also across the subsequent blocks, and this is probably because the task was relatively easy, and therefore did not benefit much from more extended practice. The fact that the RT function was not flat in the first active block of Experiment 1 suggests that task optimization was not yet complete after the 10 practice trials. Unfortunately, because of an error in the software code of Experiment 1, we did not store the data of the corresponding practice block, and therefore we cannot directly confirm our speculation. However, the problem was remediated in Experiment 5, and the results indeed showed that when task optimization was completed during the practice trials, the subsequent RT function in the distractor-absent condition during the first active block was flat.

The other robust finding is that in all the experiments, with or without passive viewing, RTs in the distractor-present condition of the first active block always followed a negative exponential function. It is therefore evident that any distractor-related learning process occurring during the passive-viewing phase, which always led to reduced capture in the active blocks, had limited influence on the factors yielding such prolonged RTs in the initial trials of the first active block, when the distractor was introduced. Before we discuss this finding, it is relevant to clarify another important point related to the different pattern of RTs found in the distractor-present and distractor-absent conditions. Because the misallocation of attention caused by the distractor is typically indexed by the RT difference between the distractor-present and distractor-absent conditions, the disparity in the initial part of the two functions in Experiments 2– 6 explains the apparently enhanced capture effect observed in the initial few trials of these experiments compared with Experiment 1, wherein the two functions were identical in shape but separated by a nearly constant offset. Consequently, this suggests that to obtain an uncontaminated index of spatial capture triggered by the peripheral onset one should focus on the asymptotic part of the two functions, and we followed this approach to confirm that capture was much larger in the first active block of Experiments 1 and 5, compared with the same block of all remaining experiments in which passive viewing was introduced (see Experiments 2, 3, 4, and 6). Incidentally, one should note that the amount of capture in the first block of Experiment 1 would have been even larger if, as expected because of the practice trials, the RT function in the distractor-absent condition had been flat, as indeed observed in all the other experiments.

We now return to the fact that, contrary to the distractor-absent condition, the distractor-present condition revealed an initial RT cost that dissipates in a few trials. Obviously, this initial cost exists in spite (and regardless) of the passive-viewing phase. If, as it seems safe to assume, the rapid-decay negative exponential RT function observed in the practice blocks of all experiments reflects a rapid task optimization (e.g., optimal S-R mapping), one might be tempted to conclude that such optimization process had to start anew when the distractor was introduced at the beginning of the first active block, namely in a new "context" defined by the distractor presence. However, we have argued that this explanation is unlikely because, if this were the case, then one might predict to observe a similar RT pattern also in the distractor-absent condition. In fact, should the S-R mapping be relearned within the new context, namely a task paradigm wherein a salient distractor is presented on half the total trials, this ought to impair performance to a similar degree in the distractor-absent and distractor-present condition of the new context, but this is clearly not the case. Therefore, we think it safe to reject this possibility. In a similar fashion, changing from perceiving the distractor in a passive-viewing context to perceiving the same distractor in the context of an active task might cause a temporary recovery of the habituated capture, in agreement with the observation that habituation of attentional capture is (spatial) context dependent (Turatto et al., 2018). However, this possibility seems to be undermined by the observation that the same RT pattern emerged also in Experiment 5, when the passive viewing was omitted, and any habituation to the distractor prior to the active task can be excluded. As a further alternative, the one we tend to favor, the initial slowness in responding could reflect a transient conflict between the representation of the target and that of the distractor—a conflict that participants learned to resolve in a few trials. The concurrent presence of two salient elements is in fact known to give rise to nonspatial object-based competition (Duncan, 1984; Treisman et al., 1983; van Boxtel & Koch, 2012), and this competition may entail a cost during the initial few trials. The current set of experiments does not allow us to distinguish conclusively among these three alternatives. However, based on the above discussion, we argue that the latter possibility provides a more likely explanation of the observed pattern of performance. At any rate, the main point here is that the initial lengthening of RTs in the first few trials of the distractor-present condition, as we found in some of our experiments, likely emerged because participants had to get used to handling the distractor within a different task context relative to the passive-viewing phase. Contextual changes, indeed, can have profound effects on different cognitive processes, like for instance, memory (Godden & Baddeley, 1975), attention (Chun, 2000), and habituation of capture and the startle reflex (Chiandetti & Turatto, 2017; Turatto et al., 2018), which sometimes appear to be context specific in both humans and other animals. By contrast, as the results of Experiment 7 indicate, habituation for a given stimulus distractor generalizes to a new discriminative task from the one under which habituation first developed.

To summarize, overall the results suggest that distractor filtering of an irrelevant visual onset, presented while participants are engaged in a focused attention task, involves two separate, but interrelated, learning processes. The first process hinges on habituation mechanisms, whereas the nature of the second process is less clear, but the current evidence suggests that it might involve learning to cope with the interference caused by the distractor (at the S-R mapping and/or object-based attention level) when it is initially encountered within the context of a new active task. Whether or not our speculations about the second process are correct, we would like the reader to note that this does not undermine the main result of our study, namely that a learning process supporting distractor rejection can take place during passive viewing, when the cognitive system is not (reactively or proactively) responding to distraction to shield target processing from interference, thus leaving a habituation-like mechanism as the most straightforward explanation for this latent-learning phenomenon.

Previously, we have systematically shown that the capture of fully focused visual attention caused by a sudden onset distractor is subject to habituation, and that this form of learning has both short- and long-term components, thus creating a link between the habituation phenomenon and the visual-attention research literature (Pascucci & Turatto, 2015; Turatto & Pascucci, 2016). We then went a step forward in documenting, for the first time, that habituation of capture was linked to the specific (geometric) context in which it took place, and that surprisingly its consequences remained unchanged for weeks (Turatto et al., 2018). In the present study, instead, we directly addressed whether the learning-dependent phenomenon leading to reduced distraction is achieved via top-down inhibitory signals strategically applied to the distractor to protect target processing from interference, as is widely assumed, or whether more automatic, habituation-like mechanisms can support reduced capture after repeated passive exposure to a given distracting stimulus. By showing that the ability to disregard distractors can be learned even during passive viewing, here we provided compelling and novel evidence in favor of a key role of habituation-like mechanisms.

Finally, a key question for future studies is whether the memory trace of the irrelevant sensory input formed during passive fixation is, at least partly, committed to attenuate distraction—as soon as this becomes necessary and beneficial to task performance, as we have shown here, or can instead, under the appropriate task conditions, be used to aid other perceptual-attentional processes, including target selection. In other words, it remains to be established whether the neural model of the irrelevant sensory input, built during passive viewing, is inevitably committed to the filtering of the unwanted information, or rather the model is stored in a more "neutral" format, whose ultimate nature (inhibitory vs. facilitatory) and function (distractor filtering vs. target processing) will be commanded by the future task conditions.

Context of the Research

Recent research on distractor filtering in the visual domain has typically assumed that the underlying mechanisms are recruited strategically to shelter target processing from interference (Gaspelin & Luck, 2018; Marini et al., 2013). In particular, this is true in studies exploring learning-dependent reductions in distractor interference (Ferrante et al., 2018). In essence, the idea is that mechanisms for distractor filtering—including when they are enhanced through learning—are engaged as a result of a top-down mechanism that invests cognitive resources to support efficient task performance. At the same time, recent work from our labs (Pascucci & Turatto, 2015; Turatto & Pascucci, 2016; Turatto et al., 2018) has highlighted the importance of more basic habituation-like mechanisms to support distractor filtering as a consequence of repeated exposure to a given distracting stimulus. We then thought of primary importance to arbitrate between such contrasting views: Does learning-mediated distractor filtering necessitate strategic control and active task performance, or can it occur even during passive viewing? The reported data clearly show that the cognitive system can learn to disregard irrelevant, albeit salient, distractors while doing nothing, which finds a straightforward explanation in habituation-like mechanisms automatically implemented to effectively reduce distractor interference. Future efforts from our groups will assess the boundary conditions for any additional contribution of strategic and cognitively demanding mechanisms to learning-dependent distractor filtering.

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Received September 12, 2017
Revision received July 31, 2018
Accepted August 4, 2018 ■