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The Costly Filtering of Potential Distraction: Evidence for a Supramodal Mechanism

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When dealing with significant sensory stimuli, performance can be hampered by distracting events. Attention mechanisms lessen such negative effects, enabling selection of relevant information while blocking potential distraction. Recent work shows that preparatory brain activity, occurring before a critical stimulus, may reflect mechanisms of attentional control aimed to filter upcoming distracters. However, it is unknown whether the engagement of these filtering mechanisms to counteract distraction in itself taxes cognitive-brain systems, leading to performance costs. Here we address this question and, specifically, seek the behavioral signature of a mechanism for the filtering of potential distraction within and between sensory modalities. We show that, in potentially distracting contexts, a filtering mechanism is engaged to cope with forthcoming distraction, causing a dramatic behavioral cost in no-distracter trials during a speeded tactile discrimination task. We thus demonstrate an impaired processing caused by a potential, yet absent, distracter. This effect generalizes across different sensory modalities, such as vision and audition, and across different manipulations of the context, such as the distracter's sensory modality and pertinence to the task. Moreover, activation of the filtering mechanism relies on both strategic and reactive processes, as shown by its dynamic dependence on probabilistic and cross-trial contingencies. Crucially, across participants, the observed strategic cost is inversely related to the interference exerted by a distracter on distracter-present trials. These results attest to a mechanism for the monitoring and filtering of potential distraction in the human brain. Although its activation is indisputably beneficial when distraction occurs, it leads to robust costs when distraction is actually expected but currently absent.

Keywords: spatial attention, strategic filtering, distracter suppression, crossmodal interactions, cognitive load

Distraction is part of everyday life and typically leads to both errors and slowing down of responses, sometimes causing serious consequences under critical circumstances. Normally, distraction is contrasted by focusing cognitive resources on task-relevant information, in order to try and counteract the impact of distraction on performance.

From a scientific perspective, uncovering how the brain deals with distraction—actual or foreseen—represents a major challenge. Distracting information exerts a negative effect on attentional processing even when it is task-irrelevant, as revealed by behavioral (S. Forster & Lavie, 2008; Lavie & Cox, 1997; Theeuwes & Burger, 1998; Theeuwes & Godijn, 2002), neurophysiological (Reynolds, Chelazzi, & Desimone, 1999), and neuroimaging (Kastner, De Weerd, Desimone, & Ungerleider, 1998) studies. The "biased competition" account provides evidence for a mechanism of attentional control in the visual system (Desimone, 1998; Desimone & Duncan, 1995; Reddy, Kanwisher, & VanRullen, 2009). According to that model, a control is exerted by biasing competitive interactions among multiple stimuli in favor of the relevant one (see also Hopfinger, Buonocore, & Mangun, 2000; Kastner & Ungerleider, 2001). Suppressed processing of distracters is a direct consequence of such competitive unbalance. However, the model does not predict any specific and independent mechanism for the active filtering of distracting stimuli. Yet when the brain deals with a context in which distraction is expected, one might wonder whether our cognitive systems are capable of adopting

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a strategic control in order to suppress distraction and, in that case, whether activating such control might entail a behavioral cost.

At least two general mechanisms can be hypothesized to intervene when we deal with a relevant task in a potentially distracting context. First, the brain might cope with distracters at the moment they occur, for example, by contingently trying to suppress their processing (Awh, Matsukura, & Serences, 2003) or by temporarily enhancing resources assigned to the main task (Carrasco, Penpeci-Talgar, & Eckstein, 2000; Yeshurun & Carrasco, 1998), or both. Alternatively, when distraction is foreseen, neural systems might adopt a preventive rather than a proactive strategy, by constantly engaging part of the attentional resources for the suppression of potential distraction. In this regard, the analysis of pre-stimulus BOLD signal in fMRI paradigms revealed that preparatory activity may index distracter suppression (Serences, Yantis, Culberson, & Awh, 2004). When salient distracters must be ignored, a circuit linking intraparietal sulcus (IPS) to extrastriate visual cortex shows enhanced pre-stimulus activity, likely to prevent a saliency-driven response (Mevorach, Hodsoll, Allen, Shalev, & Humphreys, 2010). Indeed, brain activity prior to stimulus onset has been shown to be predictive of subsequent performance (Mazaheri, DiQuattro, Bengson, & Geng, 2011), and it may thus reflect a strategic mechanism of attentional control (Capotosto, Babiloni, Romani, & Corbetta, 2009). However, the way in which such preparatory activity directly relates to behavior is still unclear.

We therefore hypothesized that, in potentially distracting contexts, the brain is able to prevent interference from distracters by engaging a mechanism specifically aimed to filter out forthcoming distracters. The aim of our study is to disclose the behavioral fingerprint of an attentional control system that deals with forthcoming distraction. The activation of this putative filtering mechanism might require the allocation of attentional resources and increase the overall attentional load (Lavie, Hirst, de Fockert, & Viding, 2004), thus taking away resources from the primary task. Nonetheless, engaging this mechanism would be advantageous for behavioral performance, particularly when distraction is likely to occur. Consequently, such attentional filter might be engaged to different extents depending on the given circumstances, such as due to the likelihood of distracters occurrence. When forthcoming distraction is probable, this filtering mechanism might be strategically recruited throughout the whole task period, whereas when it is unlikely, reactive activation of the attentional filter upon detection of actual distraction might be a more convenient approach to achieve distracters suppression. We tested these two latter predictions in Experiments 1 and 2, respectively. Furthermore, in Experiments 3 and 4, we aimed to characterize what aspect(s) of the distracting stimuli this mechanism is intended to deal with.

Finally, given that our environment is essentially multisensory, and the brain is tuned to optimally combine cues from multiple sensory modalities (Arrighi, Marini, & Burr, 2009; Stein & Meredith, 1993), as well as to segregate them under certain circumstances (Calvert, Spence, & Stein, 2004; Kadunce, Vaughan, Wallace, Benedek, & Stein, 2001), a mechanism for the monitoring and filtering of forthcoming distraction is most likely to exert its influence over multiple combinations of stimuli and distracters from different sensory modalities. We reasoned that the context-driven activation of the mechanism in question is therefore likely to take place with distracters occurring both within and between sensory modalities, and we thus developed a crossmodal visuo-tactile paradigm, since interactions between vision and touch have already been well established in spatial attention (Macaluso, Frith, & Driver, 2000; Macaluso, Frith, & Driver, 2002). We used tactile targets and visual distracters in Experiments 1–4. We then aimed to generalize the results to different sensory modalities, in Experiment 5, and to a completely different experimental paradigm, in Experiment 6. Finally, in Experiment 7, we tested and rejected an alternative hypothesis for explaining our findings.

General Method

We used a paradigm where a distracter's presence is not predictable; therefore, an attentional system coping with forthcoming, potential distraction must deal with uncertainty. Our experimental design comprised two separate sessions for each participant (see Figure 1B): One session ("pure session") comprised only distracter-absent unimodal trials (Distracter Absent-Only, DA-O), while another session ("mixed session") contained distracter-

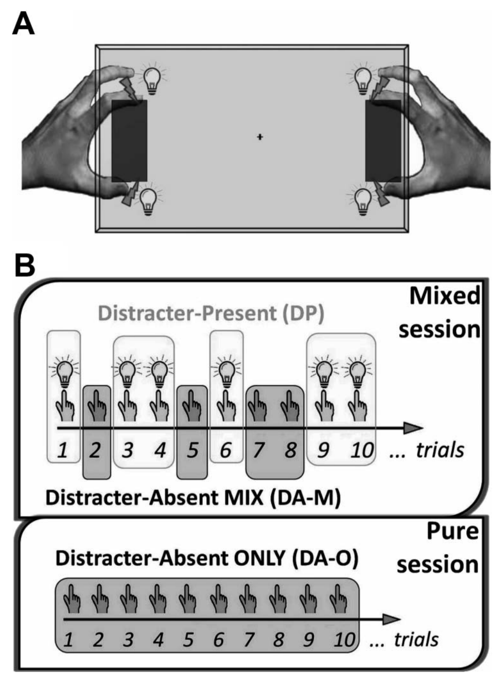

Figure 1. A. Schematic representation of the experimental setup for Experiments 1 and 2. The dart symbols represent positions of the tactile stimulators. The lamp symbols represent positions of the visual distracters. Participants held two foam blocks (dark rectangles) with their left and right hands, by placing their index fingers on the upper tactile stimulators and their thumbs on the lower tactile stimulators. Only one tactile stimulation was delivered in each trial, accompanied by a visual distracting stimulation in distracter-present trials. B. Examples of trial sequences in the two experimental sessions of all experiments. The Mixed session comprised distracter-absent trials (Trials 2, 5, 7, and 8 in the shown example) intermixed with distracter-present trials (Trials 1, 3, 4, 6, 9, and 10 in the shown example). The Pure session was constituted by distracter-absent trials only. The ratio between distracter-absent and distracter-present trials was 1:2 in Experiments 1, 3, and 4, and it was 2:1 in Experiment 2. The actual order of presentation was randomized.

absent unimodal trials (Distracter Absent-Mixed, DA-M) intermixed with distracter-present trials (Distracter-Present, DP). The rationale for this design is that engagement of a strategic filtering mechanism could be masked on distracter-present trials, but it should lead to a measurable cost in distracter-free trials embedded within a potentially distracting context (i.e., mixed session), compared to the same distracter-free trials within an entirely distracter-free context (i.e., pure session).

Participants

One hundred twenty-six young healthy participants took part in Experiments 1–7. Ten participants were excluded from analysis because of their inability to use the foot-pedal response device (see below). Twenty participants (age: 25.4 ± 5.7, 16 female, 19 right-handed) participated in Experiment 1. Sixteen participants participated in each of Experiments 2 (age: 25.4 ± 5.7, 14 female, 14 right-handed), 3 (age: 25.7 ± 9.7, 12 female, 15 right-handed), 4 (age: 24.8 ± 7.1, 11 female, 14 right-handed), 5 (age: 25.4 ± 4.1, 12 female, 15 right-handed), 6 (age: 27.7 ± 9.5, 9 female, 15 right-handed), and 7 (age: 26.8 ± 2.7, 12 female, 14 right-handed).

All participants had normal or corrected-to-normal vision, were naïve as to the purpose of the research and the experimental procedure, and gave their informed consent to take part in the study. The study was approved by the ethical committee of the University of Milano—Bicocca, Milan, Italy, and it was conducted in accordance with the Declaration of Helsinki (World Medical Association, 1996).

Stimuli

The experimental apparatus for Experiments 1–4 consisted of a vertical panel in which two foam blocks (8 × 4 × 3 cm) were fixed to the left and the right side of a central fixation point, at a lateral distance of 25 cm. Two vibrotactile stimulators (custom-made electromagnetic solenoids, Heijo Electronics, Beckenham, United Kingdom) were embedded in each block, at the top and the bottom of the lateral side of the frontal aspect of each block. Visual distracters consisted of flashes from red light emitting diodes (LEDs). The experimental setup is represented in Figure 1A. Both vibrotactile and visual signals consisted of three 30-ms single pulses interleaved with two 30-ms off-phases, resulting in a total duration of 150 ms for each stimulus. In all visuo-tactile experiments, visual stimulation led tactile stimulation by 30 ms, as this stimulus-onset-asynchrony (SOA) was previously shown to be the most effective in a similar paradigm (Spence, Pavani, & Driver, 2004). The adoption of this small SOA is intended to achieve perceptual simultaneity for visual and tactile stimuli, as the visual system has longer transduction latencies than the somatosensory system (see Shore, Barnes, & Spence, 2006, for a discussion).

In Experiments 5 and 7, we modified the same apparatus by replacing the tactile stimulators with two loudspeakers, located one on the left and one on the right side of the central midline (eccentricity: 25 degrees), near the lateralized visual distracters, and occluded by an opaque shield. Visual stimuli were the same as previously described, while auditory stimuli consisted of three 30-ms pure-tones (frequency: 587 Hz) interleaved with two 30-ms silent periods, resulting in a total duration of 150 ms for each stimulus. Auditory signals in Experiment 5 were completely lateralized (i.e., they came at 100% of intensity either from the left or the right speaker), while in Experiment 7 they were partially lateralized (i.e., a "right" stimulus came at 53% of intensity from the right speaker and at 47% from the left speaker, and vice versa; see Figure 5). In both experiments, auditory and visual stimuli were delivered simultaneously (SOA = 0).

Experiment 6 used a computer-based arrow flanker task (e.g., Ridderinkhof et al., 2002) with visual stimuli presented on the computer screen (size: 17 in. [43.18 cm], resolution: 1024 × 768, refresh rate: 60 Hz). Stimuli were up- or down-pointing arrows, presented centrally. A single target arrow was displayed in distracter-absent trials, while the target arrow was flanked by four simultaneous distracting arrows (two on the left and two on the right) in distracter-present trials. The orientation of flankers could be either congruent or incongruent with respect to the direction of the central target arrow (see Figure 6a).

The orders of sessions, as well as the trial sequence within each session, were randomized. In distracter-present trials of all experiments, every possible spatial combination of target-distracter was delivered with equal probability. Presentation and timing of both the tactile and the visual stimuli were under computer control (through a custom-made I/O stimulator box, E-Studio software; Psychology Software Tools, Sharpsburg, PA).

Task

Experiments 1–4. We ran a tactile elevation discrimination task in a similar vein to the one previously used to investigate the crossmodal congruency effect (Maravita, Spence, & Driver, 2003). Participants sat in front of a table, at a distance of 57 cm from the central fixation point. They placed their forearms on the table and held the foam cubes (one in each hand), keeping their index fingers on the upper vibrotactile stimulator and their thumbs on the lower stimulator. On each trial, participants received vibrotactile stimulation at one out of four possible locations. They were asked to judge the elevation of the tactile stimulus (high/low), regardless of the stimulation side (left/right). Participants gave speeded elevation discrimination responses to the vibrotactile targets, while ignoring the distracters, if present. The visual distracters, when present, were equally likely to occur at the same or at a different elevation compared to targets, hence distracter-present trials (DP) could contain either a congruent (DP-C) or an incongruent (DP-I) distracter, respectively. The experimenter visually checked that participants maintained their eyes open and directed at fixation throughout all experiments. Responses were delivered through two foot pedals, one below the participants' tiptoe and one below their heel, and participants were to raise the tiptoe to respond "high" (index finger stimulus) or the heel to indicate "low" (thumb stimulus). The same foot-pedal method was used to collect responses in many previous studies using the same task (e.g., Heed, Habets, Sebanz, & Knoblich, 2010; Spence et al., 2004). Measures of response accuracy (Acc) and reaction times (RT) were collected. The total duration of the task was about 30 min.

Experiments 5 and 7. These experiments differed from Experiments 1–4 in that participants were required to indicate the side (right/left) of the auditory stimulus while ignoring any visual distracter that occurred either on the same (congruent, DP-C) or on the opposite side (incongruent, DP-I). Responses were delivered manually by pressing a key ("z" or "m") on the computer keyboard. Accuracy and reaction times were recorded. The time required for completing the task was about 30 min.

Experiment 6. Participants were asked to report the orientation of a central arrow (pointing up or down) by pressing a key ("k" or "m") on the keyboard. In distracter-present conditions, the target arrow was flanked by either congruent or incongruent distracting arrows. We measured accuracy and reaction time. The global duration of this task was about 20 min.

Analysis

Statistical analyses were executed by means of two-tailed *t* tests for pairwise comparisons or analysis of variance (ANOVA) for cases with more than two levels in the independent variable. Accuracy values were preliminarily transformed into the arcsine of the square root by using the Freeman-Tukey correction (Freeman & Tukey, 1950). Reaction times (RTs) were filtered to eliminate outliers, excluding all trials below values of 250 ms (anticipatory responses) as well as all trials exceeding two standard deviations above the mean (late responses), computed separately for each participant and condition in log-values to overcome the typical asymmetry of the RT distribution (Ratcliff, 1993). Possible speed–accuracy trade-offs were controlled for by calculating the inverse efficiency (IE) score (Townsend & Ashby, 1983). Normality and kurtosis of the data distributions were checked and all values were <2. When significant effects emerged, the effect size was computed by calculating the relative eta-squared index (η^2). In ANOVA, post hoc comparisons, when appropriate, were conducted with Tukey's highly significant difference (HSD) test.

Experiment 1

In this experiment, we aimed to test whether, in a context in which visual distraction is likely, the attentional systems might engage a strategic mechanism to filter out forthcoming distracters, leading to a behavioral cost even when distraction is currently absent. The likely distracting context was established by making the probability of distracter occurrence in the mixed session twice as high as the probability of distracter absence; specifically, DP trials occurred twice as frequently as DA-M trials (i.e., their proportion was 2:1).

First, we ran a direct comparison between trials with and without distracters from the mixed session, in order to verify that the distracting visual stimuli actually exerted a disturbing effect on tactile performance. Here, we used a one-way ANOVA factoring the type of trial in the mixed session (DA-M, DP-C, DP-I), which turned out to be highly significant, $F(2, 38) = 102.5$, $p < .001$. The post hoc analysis showed that, when incongruent distracters were present, responses to target stimuli were slowed down (DP-I = 559 ms) compared to both DA-M (DA-M = 479 ms) and DP-C conditions (DP-C = 473 ms; $p < .001$; see Figure 2A). No reliable difference between DA-M and DP-C conditions was observed. Here and in all subsequent experiments, we considered the difference in RTs between DP-I and DP-C trials as an index of *distracter interference* (mean distracter interference equaled to 86 ms in Experiment 1). We also observed a main effect of *condition* within the mixed session in relation to accuracy, $F(2, 38) = 74.1$, $p < .001$. Post hoc comparisons revealed that participants were significantly more prone to making errors in DP-I trials compared to both DA-M ($p > .005$) and DP-C trials ($p < .005$). Mean error rates were 16.4% for DP-I, 2.6% for DP-C and 3.8% for DA-M trials.

Given that the presence of measurable distracter interference was a prerequisite for our hypothesis to be tested, we then compared the two distracter-free conditions belonging to different contexts, following the hypothesis of a selective cost in the DA-M condition, relative to the DA-O condition, due to the costly engagement of a distracter filtering mechanism in the former condi-

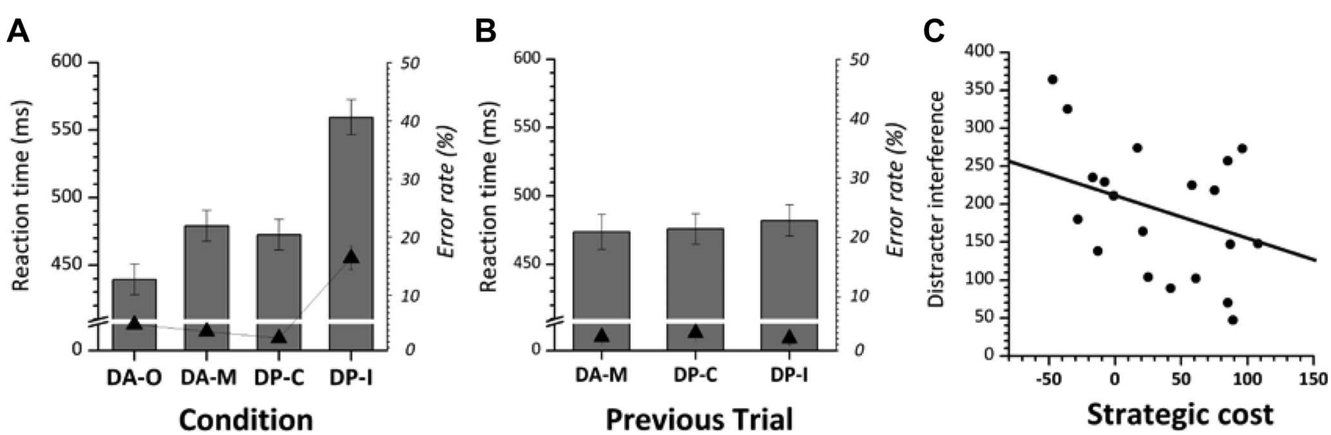

Figure 2. A. Reaction times (RTs; represented by columns, left-side axis) and error rates (represented by triangles, right-side axis) in Experiment 1, separately for each condition: distracter-absent only (DA-O), distracter-absent mixed (DA-M), distracter-present congruent (DP-C), and distracter-present incongruent (DP-I). The difference between DA-M and DA-O (RTs: $p < .001$) is a measure of the strategic cost, while the difference between DP-I and DP-C (RTs: $p < .001$) indexes distracter interference. Error bars represent standard error. B. Reaction times (represented by columns, left-side axis) and error rates (represented by triangles, right-side axis) to distracter-absent mixed trials in Experiment 1, separated on the basis of the preceding trial type: DA-M, DP-C, and DP-I. No significant difference emerged. C. Dots depict individual correlation points between the strategic cost and the distracter interference ($p < .05$). The solid line depicts the least-squares fit for the data as calculated by means of a simple linear regression model. All values were computed as inverse efficiency (IE) scores.

tion. As predicted, the potentially distracting context affected performance in DA-M trials, compared to DA-O trials, inducing an average RT cost of 40 ms (average: DA-O = 439 ms, DA-M = 479 ms), $t(19) = 4.43$, $p < .001$, $\eta^2 = 0.71$.[1] Response accuracy was marginally higher for the DA-M condition, compared to the DA-O condition, $t(19) = 2.23$, $p = .04$, $\eta^2 = 0.45$ (see Figure 2A). Since the latter result might suggest the existence of a speed–accuracy tradeoff, we also compared the inverse efficiency score and still found a significant cost under the DA-M condition, compared to the DA-O condition, $t(19) = 3.14$, $p < .01$, $\eta^2 = 0.58$, showing that the difference in RTs was not due to shifts in response criterion. However, it might be claimed that a possible criterion shift is masked by a ceiling effect in accuracy in the present experiment. Experiment 7 has been specifically designed to directly address this issue (see below).

Mean RTs and error rates for all experiments and conditions are shown in Table 1. If participants had relied on enhanced target processing in order to deal with potential distraction, that should have led to an optimal performance in DA-M trials, compared to DA-O ones. In fact, we observed the opposite pattern, with a relative cost in DA-M trials, thus suggesting the involvement of a distracter suppression mechanism that also affected performance in distracter-free trials. These results demonstrate for the first time that the attentional processing of target stimuli is sometimes severely impaired when distraction is expected but actually absent.

A candidate account of our findings relates to the notion of *post-error slowing* (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Since error rates were globally higher in the mixed session (due to errors in DP-I trials), we needed to examine whether the observed slowing-down of responses to DA-M trials was a consequence of post-error slowing. In order to examine performance on trials that follow errors, we analyzed DA trials (both in the "pure" and in the "mixed" session) as a function of response accuracy in the previous trial. This originated a 2 × 2 ANOVA factoring Session (pure/mixed) and Previous Trial Response (correct/incorrect). The analysis revealed a significant main effect of Previous Trial Response, $F(1, 19) = 34.9$, $p < .001$, with RTs to DA trials after errors being longer than those after correct responses (post-error slowing). Also, the main factor Session was significant, $F(1, 19) = 7.9$, $p = .01$, confirming that DA-M trials led to longer RTs compared to DA-O trials. Crucially, no interaction was observed between Session and Previous Trial Response, $F(1, 19) = 0.41$, $p = .71$, indicating that the observed strategic cost (i.e., the slowing down of responses in DA-M trials compared to DA-O) was independent of the preceding trial response. These results show that participants were overall slower after errors, compared to correct responses, but also that post-error slowing does not account for the observed strategic cost.[2]

At this point one may ask whether the observed cost on distracter-free trials in the potentially distracting context and the interference exerted by distracters (especially when incongruent) actually are the two faces of the same coin. If a filtering mechanism is engaged to cope with distraction and that results in a cost even when distraction is expected yet currently absent, it should be possible to establish a relation between these two costs. In particular, participants who strongly engage the filtering mechanism should suffer less from actual distracters compared to participants recruiting this mechanism to a lesser extent. We tested such prediction by means of a correlation analysis on a per-participant basis, directly comparing the *strategic cost*, defined as the difference between DA-M and DA-O trials, and the mean distracter interference, computed as described above. Since RTs and accuracy data showed a divergent tendency in this experiment, we chose to run the correlation analysis on inverse efficiency scores, which combine the two measures and therefore provide a more reliable overall index of performance. A significant inverse correlation emerged between these two variables, $r(18) = -0.46$, $p < .05$, as shown in Figure 2C. It appears that, the more strongly one engages the mechanism to filter out potential distraction, the less his or her performance will be impaired when distraction actually occurs, and vice versa.

In order to explore whether activation of the filtering mechanism relies on truly strategic processes, we assessed its potential dependence on contingencies occurring along the trial sequence. In fact, our results might reflect either a strategic or a contingent mechanism for the suppression of distracters. If the latter, the cost on DA-M trials would likely increase in DA-M trials following a DP trial, compared to those following another DA-M trial. Moreover, the greatest reactive activation should likely be observed after a DP-I trial, since incongruent trials generate a higher degree of conflict for responding than DP-C trials. We then sorted DA-M trials on the basis of the preceding trial type, subdividing DP trials into DP-I and DP-C trials, and performed a one-way ANOVA factoring Previous Trial with three levels (DA-M, DP-C, DP-I). This analysis showed that the preceding trial type did not reliably affect RTs in the DA-M condition, $F(2, 38) = 2.12$, $p = .13$ (see

Table 1
Mean Reaction Times (in ms) and Error Rates (Percentage, in Parentheses) for All Experiments and Conditions

Experiment	DA-Only	DA-Mix	DP-Congruent	DP-Incongruent
1	439 (5)	479 (3.7)	473 (2.6)	559 (16.4)
2	457 (4.7)	483 (3.8)	490 (2.6)	586 (15.4)
3 (AB)	426 (8)	468 (8)	449 (4.6)	521 (25)
3 (AC)	426 (8)	460 (8.1)	452 (13)[a]	
4	433 (3.8)	466 (3)	482 (3.2)	561 (16.8)
5	386 (1.6)	507 (3)	527 (4.4)	641 (33.5)
6	380 (3)	410 (1.9)	425 (1.6)	467 (6.1)
7	540 (13.9)	647 (19.3)	624 (10.1)	757 (58.8)

Note. DA = distracter-absent; DP = distracter-present; AB = Conditions A and B; AC = Conditions A and C.
[a] Note that in Experiment 3 (Condition C) distracters were neither congruent nor incongruent with the target elevation, as there was a single distracter at fixation.

[1] We reanalyzed the critical conditions (i.e., DA-O and DA-M) of this and the subsequent experiments (2–4) by filtering RTs with a superior cutoff of 4 *SD*s above the mean (thus with a theoretical probability of excluding valid trials of less than 10^{-4}). We again found a significant difference between DA-O and DA-M conditions in all experiments (Experiments 1, 3, 4 ps < 0.01; Experiment 2 $p = .05$).

[2] Since the number of DA-O and DA-M trials was the same, the whole mixed session was three times as long as the pure session. In order to exclude a potential confound due to a decrease in sustained attention during the "long" intermixed session, we split the intermixed session in three parts and found that RTs became *faster* along the session (probably reflecting a learning process) and not slower, as a decrease in sustained attention would predict.

Figure 2B, columns). We also found that the preceding trial type did not reliably affect error rates (see Figure 2B, triangles), $F(2, 38) = 0.54$, $p = .59$.

Finally, we examined whether session order impacted performance by running an ANOVA on the DA-Only session factoring Order (first vs. second, between participants) and Mini-Block[3] (1 to 6, within participant). Both factors led to a significant main effect. More specifically, Order revealed that the first session was slower than the second one, $F(1, 15) = 11.9$, $p < .005$, reflecting a general practice effect. Also the factor Mini-Block was significant, $F(5, 75) = 2.6$, $p < .05$. Post hoc analyses revealed that the first mini-block of each session was slower than the second one ($p < .05$), yet it was not different from the subsequent four mini-blocks. No interaction was observed between Order and Mini-Block ($p = .92$).

It thus appears that participants adopted a strategy to deal with probable forthcoming distraction throughout the mixed session, by allocating part of their attentional resources to prevent interference. That strategy increases the attentional load (Lavie et al., 2004), thus reducing available resources for target processing, leading to the observed slowing-down of DA-M responses. If so, the involvement of such strategy should be modulated by the distracters' probability, becoming less convenient when they are relatively unlikely to occur. We tested this prediction in the following experiment.

Experiment 2

One might conjecture that the absence of any contingent effect of the previous trial on DA-M trials, as found in the previous experiment, can be explained by the relatively high frequency of DP trials compared to DA-M trials. In this context, the best solution to cope with frequent distracters might well be to engage a strategic filtering mechanism along the whole session. However, when distraction is less likely, a reactive activation of the filtering mechanism upon detection of a distracter might be the optimal strategy.

The aforementioned prediction was tested in Experiment 2. We replicated the design of Experiment 1, introducing only one major change: Here, DA-M trials were embedded in a context with less likely distracters, since we reversed the number of DP and DA-M trials (i.e., their proportion is now 1:2). We hypothesized that, when distraction is less likely, the mechanism for distracters' filtering is engaged primarily through a reactive dynamics and perhaps to a lesser extent overall.

Results showed a moderate slowing-down of DA-M responses compared to DA-O responses (DA-O = 457 ms, DA-M = 483 ms), $t(15) = 2.52$, $p < .05$, $\eta^2 = 0.55$ (see Figure 3A), and the effect was weaker than in Experiment 1. No differences emerged in response accuracy, $t(15) = 1.77$, $p = .11$. The mean distracter interference effect amounted to 96 ms in this experiment, $t(15) = 9.87$, $p < .001$. Noticeably, the RTs-cost observed in DA-M trials compared to DA-O trials did not emerge on IE scores, $t(15) = 1.50$, $p = .15$. The latter measure, which allows to neutralize the potentially confounding effects of criterion shifts, is therefore revealing a null effect here (in contrast to Experiment 1), thus demonstrating that the filtering mechanism is recruited to different degrees depending on the probability of occurrence of distracters during the session. Therefore, this pattern of results fully confirms our hypothesis, highlighting that any strategic mechanism of distracters' filtering is more relaxed when distraction is still possible but relatively improbable.

To explore whether the activation of this filtering mechanism under low distracters' probability primarily relies on a reactive dynamics, as hypothesized, we compared the cost of the mixed session (i.e., DA-M minus DA-O) on trials following either a distracter-absent or a distracter-present trial. We observed a significant effect of the main factor Previous Trial, $F(2, 30) = 8.81$, $p < .001$, and post hoc tests revealed a higher behavioral cost in DA-M trials preceded by DP-I trials compared to those preceded by both DP-C ($p < .05$) and DA-M ($p < .001$), whereas no difference was found between DA-M trials preceded by DA-M versus DP-C trials ($p = .41$; see Figure 3B). Therefore, unlike what we found for Experiment 1, where we showed that the previous trial type did not reliably modulate the behavioral cost observed on DA-M trials, the present results clearly demonstrate a difference in the behavioral cost depending on the type of the preceding trial, with the greatest cost following DP-I trials. We then examined whether the mixed cost was still significant when contrasting DA-O trials with DA-M trials preceded by another DA-M trial. This analysis is aimed to test whether a strategic activation of the filtering mechanism occurs when distracters are relatively infrequent, while discounting the reactive component of the filtering activation. This analysis did not reach significance level ($p = .08$), showing that the observed mixed cost in Experiment 2 critically depends on the reactive engagement of the filtering mechanism.

Overall, these results clearly show that the filtering mechanism is activated in different ways and to differing degrees on the basis of probabilistic information. They show that the filtering mechanism is predominantly recruited in a strategic manner when distraction is highly probable. Instead, when distraction is less likely, the system is more "relaxed" and mainly relies on reactive activation of the filtering mechanism upon detection of a distracting event.

Experiment 3

With the previous experiments, we provided solid behavioral evidence for the existence of an attentional mechanism that is engaged whenever we deal with potentially distracting contexts in order to counteract the cost on performance induced by distraction. We showed that, in a tactile discrimination task, the presentation of visual distracters determined a slowing-down of the elevation judgments when target and distracters occurred at opposite up/down locations (incongruent trials). Moreover, we disclosed that the human brain engages strategic and reactive filtering mechanisms aimed at preventing this behavioral cost. However, it is still not clear what perceptual or response-related properties of the distracting stimulus are essential to engage the latter mechanism.

When a distracter matches some perceptual properties of the target, or is somehow associated with a conflicting behavioral response, it induces greater interference, likely because of lower target discriminability and greater response competition, respec-

[3] The DA-Only session (128 trials) was split into six subsequent mini-blocks, comprising 21 trials each (Blocks 5 and 6 actually comprised 22 trials each).

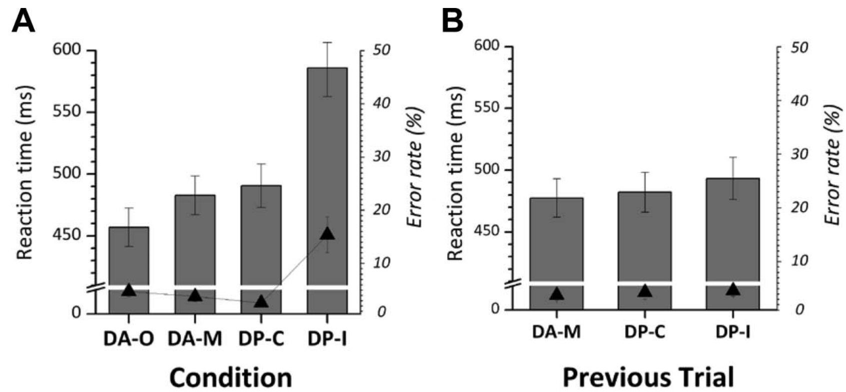

Figure 3. A. Reaction times (RTs; represented by columns, left-side axis) and error rates (represented by triangles, right-side axis) in Experiment 2, for the two critical distracter-absent conditions, distracter-absent only (DA-O), and distracter-absent mixed (DA-M; RTs: $p < .05$). B. Reaction times (represented by columns, left-side axis) and error rates (represented by triangles, right-side axis) to distracter-absent mixed trials in Experiment 2, separated on the basis of the preceding trial type: DA-M, distracter-present congruent (DP-C), distracter-present incongruent (DP-I). Responses were significantly slower following a DP-I trial, compared to trials subsequent to both DA-M ($p < .001$) and DP-C ($p < .05$) trials. Error bars represent standard error.

tively (Desimone & Duncan, 1995; Duncan & Humphreys, 1989; Eriksen, Coles, Morris, & O'Hara, 1985; Serences et al., 2005). In particular, given the typical features of the crossmodal congruency task, the critical distraction determined by spatially incongruent visual distracters on the tactile elevation judgment is known to be influenced by both spatial attention, being stronger when distracters are close to the hand receiving the touches, compared to the contralateral hand, and response conflict (B. Forster & Pavone, 2008; Spence et al., 2004). Consequently, a mechanism for preventing such interference might depend on spatial-related characteristics, response-related characteristics, or both. We then planned to clarify whether the strategic filtering of potential distraction, as revealed by the previous experiments, depends on the spatial or the motor determinants of the critical stimulus/distracter conflict. More specifically, the filtering mechanism could be driven to suppress perceptual interference deriving from the sharing of spatial locations between targets and distracters. Alternatively, it might be aimed at optimizing the response selection stage, suppressing any response tendency evoked by the distracting stimulus. Recently, a preparatory mechanism for the suppression of forthcoming distraction has been identified in monkeys (Wardak, 2011). Such endogenous proactive inhibition prevents motor responses to a subsequent event, and it is mediated by the activation of the supplementary motor area (SMA; Wardak, 2011). A proactive mechanism for the preparatory inhibition of selective response tendencies has been identified also in humans (Cai, Oldenkamp, & Aron, 2011).

We set out to perform Experiment 3 in order to test whether spatial co-localization between targets and distracters or instead their response incompatibility plays a pivotal role in the recruitment of the strategic filtering mechanism. In this experiment, we modified the paradigm of Experiment 1 by including three sessions, randomly administered to participants. One session was the DA-O session (Condition A); in another session (Condition B), the position of visual distracters was modified by placing them along the vertical meridian at a central high or low position, thus eliminating the spatial proximity with the tactile targets, but still maintaining an element of congruence (or incongruence) with the required elevation judgment (see Figure 4A, upper panel); in the remaining session (Condition C), the position of distracters was again changed, by placing the distracter at a unique central location with middle elevation (i.e., superimposed to the fixation point), thus minimizing any spatial or response-related conflict (see Figure 4B, upper panel). Importantly, in Experiment 3 the proportion of distracter-present to distracter-absent trials was set to 2:1, as in Experiment 1.

If the filtering mechanism is intended to prevent any perceptual confusion between target and distracter at their respective spatial locations, disrupting their physical proximity, as we did in Condition B, should be sufficient to prevent the filtering mechanism from being activated. Differently, if such mechanism is recruited to prevent distracter-driven response tendencies, the resulting cost should still be measured in the high-versus-low distracter session (Condition B), but it should be absent by presenting the distracter at the fixation point (Condition C). Finally, if the filtering mechanism is activated to prevent a purely exogenous shift of attention caused by the mere occurrence of a perceptual event in the visual field, the behavioral cost should be observed even in the latter condition.

The mean distracter interference effect amounted to 72 ms in Session B, $t(15) = 4.48$, $p < .001$. Of course, it was not possible to compute any distracter interference effect in Session C, because there was no congruency/incongruency of distracters with respect to the target. However, if we compare RTs to DA-M and DP trials in Session C we observe no significant difference (DA-M = 460 ms; DP = 452 ms; $p = .13$).

Analysis of the comparison between Session A and B revealed that responses for DA-M trials (average RT: 468 ms) were both slower, $t(15) = 4.60$, $p < .001$, corrected-$\alpha = .0167$, $\eta^2 = 0.76$ (see Figure 4A, lower panel) and higher in IEs, $t(15) = 3.99$, $p < .01$, corrected-$\alpha = .0167$, $\eta^2 = 0.72$, than those for DA-O trials (average RT: 426 ms), whereas this contextual effect was not

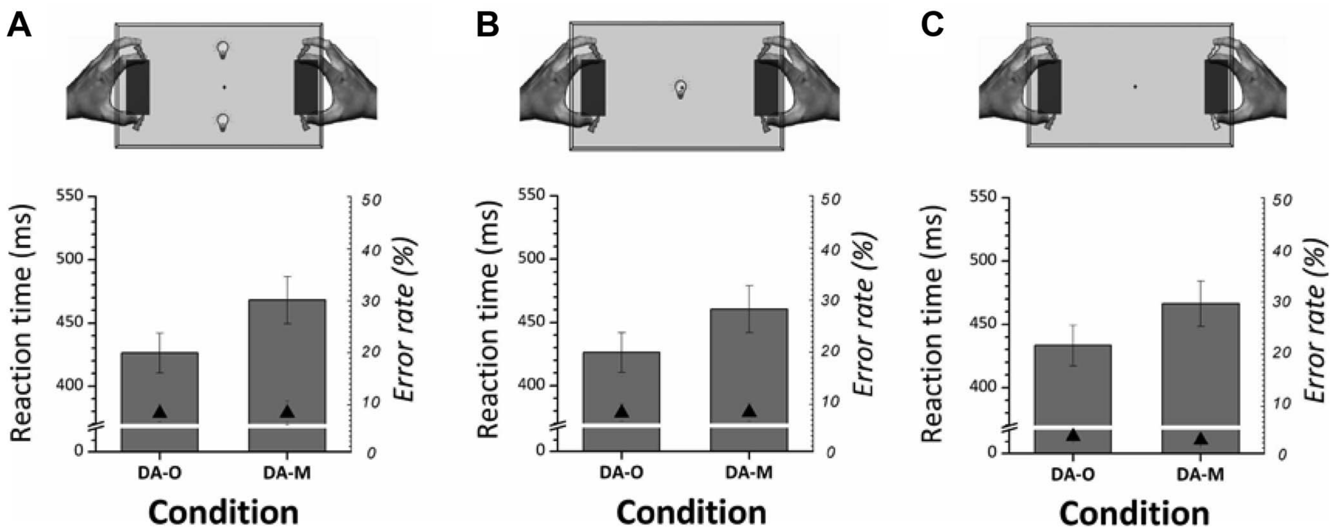

Figure 4. A. Set-up for Experiment 3 Condition B (upper panel) and results for Experiment 3 Conditions A and B (lower panel). B. Set-up for Experiment 3 Condition C (upper panel) and results for Experiment 3 Conditions A and C (lower panel). C. Set-up and results for Experiment 4. The upper part of each panel depicts a schematic representation of the experimental setup, where the dart symbols represent the position of the tactile stimulators and the lamp symbols represent the position of the visual distracters. Lower graphs show RTs (columns, left-side axis) and error rates (triangles, right-side axis) for the two critical distracter-absent conditions: distracter-absent only (DA-O) and distracter-absent mixed (DA-M). Differences ($p < .005$ for all RTs pairs) index the cost of engaging the mechanism for the strategic filtering of potential distraction. Error bars represent standard error. RT = reaction time.

modulated by the type of preceding trial, $F(2, 30) = 2.57$, $p = .09$. No differences between DA-M and DA-O trials were observed in terms of response accuracy ($p = .49$). These results highlight that a strategic mechanism for the filtering of potential distracters is engaged even when target and distracting stimuli are spatially separated, thus such mechanism is likely not intended to prevent a potential perceptual integration between target and nontarget stimuli (Spence et al., 2004). However, since distracters could still be congruent or incongruent with respect to the targets in terms of response tendencies, it is possible that the functional significance of this filtering mechanism principally concerns the blocking of distracter-driven response tendencies. Consequently, in Session C the distracter was rendered entirely irrelevant in terms of both spatial position and response compatibility, and therefore, there should be no need for suppressing any competing motor response tendency and no need to call into play a mechanism for the proactive filtering of potential distraction. The comparison between Sessions A and C showed that responses to distracter-absent trials were reliably faster in the DA-O than in the DA-M session (average RTs: 426 ms vs. 460 ms), $t(15) = 3.59$, $p < .005$, corrected-$\alpha = .0167$, $\eta^2 = 0.68$ (see Figure 4B, lower panel), and such difference was also significant in terms of inverse efficiency scores, $t(15) = 3.61$, $p < .005$, corrected-$\alpha = .0167$, $\eta^2 = 0.68$, while no significant differences emerged in accuracy ($p = .90$). Again, there was no reliable effect of the type of preceding trial, $t(15) = 0.46$, $p = .65$.

We thus observed a cost of the distracting context in both Sessions B and C, i.e., when distracters were spatially compatible or incompatible with the requested judgment and even when they consisted of a simple flash occurring at fixation. Consequently, the filtering mechanism does not seem to be primarily engaged to either avoid a perceptual integration of target and distracter stimuli as a consequence of their co-localization or to prevent a distracter-driven activation of conflicting response tendencies. Rather, its engagement seems to serve the primary role of counteracting an exogenous shift of spatial attention toward the irrelevant sensory information conveyed by the distracting visual stimulus.

Experiment 4

In the first three experiments, we showed that a strategic filtering mechanism prevents the cost of distraction in a crossmodal context where tactile targets are presented together with visual distracters. One might wonder whether this crossmodal context is a special case and whether our findings would generalize to contexts where distraction occurs within and not between sensory modalities. For example, it is conceivable that distraction arising from a sensory modality other than that of the target needs to be blocked by a specific mechanism of the kind we have characterized thus far, whereas within the same sensory modality a more flexible allocation of resources might entail no need to engage a specific distracting suppression mechanism. In other words, the strategic mechanism could be engaged selectively when a target from one sensory modality (i.e., tactile) competes with distracters from a different sensory modality (i.e., visual), and not when target and distracters belong to the same modality. An alternative possibility is that a within-modality distracter might compete even more strongly with target processing, because of the greater cognitive effort required to orchestrate concurrent attentional selection and filtering within the same sensory channel. If so, the occurrence of target and distracters within the same modality might lead to an even more pronounced filtering cost.

To examine whether a strategic filtering mechanism of potential distraction is recruited even within the same sensory modality, we replicated the paradigm of Experiment 1, but with both targets and distracters being tactile. In Experiment 4, one side of stimulation was assigned to targets and the opposite side to distracters, with target and distracter side being counterbalanced across participants (see Figure 4C, upper panel).

The mean distracter interference effect amounted to 80 ms, $t(15) = 6.9$, $p < .001$. Moreover, also within the tactile modality, we observed a cost exerted by the distracting context in DA-M trials, compared to DA-O trials, both in RTs (average RTs: 466 ms and 433 ms, respectively), $t(15) = 3.08$, $p < .01$, $\eta^2 = 0.62$ (see Figure 4C, lower panel) and IEs, $t(15) = 2.44$, $p < .05$, $\eta^2 = 0.53$, whereas no difference in accuracy was observed between conditions ($p = .36$). The previous trial type did not modulate such a cost, $F(2, 30) = 0.91$, $p = .41$.

The above findings suggest that the mechanism we have uncovered is not specifically involved within bimodal contexts, where the segregation of input signals from different modalities is a pre-requisite for the attentional filtering to take place. Rather, the filtering mechanism is engaged also within unimodal contexts, for instance when targets and distracters are both tactile. Moreover, the effect size is quite comparable to the one observed in the preceding experiments, suggesting that the filtering of distracters in the same sensory modality as the target is not more resources-demanding than filtering between modalities, at least in the domain of spatial attention. Therefore, with this experiment, we confirmed the existence of an attentional mechanism strategically recruited in potentially distracting contexts, dealing with unimodal as well as multimodal contexts, whose primary function seems to be that of preventing a shift of attention from the target stimulus toward an expected, forthcoming distracter.

Experiment 5

We have provided solid evidence for a mechanism aimed at preventing potential distraction within and between sensory modalities. However, target stimuli were always tactile in the previous experiments; thus, one might wonder whether these findings generalize to a different target modality. Therefore, we reasoned that, in order to strengthen the claim of a truly supramodal nature of the strategic filtering mechanism, it was essential to perform an experiment where targets were delivered in a modality other than tactile. In addition, one might wonder whether these findings are replicated when eliminating the potential influence of other minor experimental factors such as the short physical asynchrony between target and distracting stimuli, as well as the somewhat unusual foot-response modality.

In this experiment, we planned to test whether the described results can be replicated when using a different crossmodal context (audio-visual), with a different target modality (auditory instead of tactile), a different response effector (the hand instead of the foot), and an exact synchrony between target and distracting stimuli (SOA = 0).

Reaction times to DA-O trials (mean: 386 ms) were significantly faster than those to DA-M trials (mean: 507 ms), reflecting a dramatically high strategic cost, $t(15) = 7.43$, $p < .001$, $\eta^2 = 0.89$ (see Figure 5a). In addition to this cost, also a significant distracter interference effect was observed, $t(15) = 8.66$, $p < .001$, $\eta^2 = 0.91$, with RTs to DP-I trials being considerably slower than to DP-C trials (641 ms and 527 ms, respectively). In terms of accuracy, performance was nearly optimal under both distracter-absent conditions, with mean error rates of 1.6% in DA-O trials and 3% in DA-M trials, $t(15) = 1.80$, *ns*. Also in DP-C trials the participants' performance was fairly good, with a mean error rate of 4.4%, whereas performance was much worse when visual distracters were incongruent (error rate: 33.5%), $t(15) = 6.92$, $p < .001$.

These results replicated the finding of a strategic cost measured in distracter-absent trials within the context of a sound localization task with lateralized visual distracters. Similar to Experiments 1 and 2, we also performed an analysis of RTs by subdividing DA-M trials on the basis of the preceding trial type, in order to disentangle the relative contribution of strategic and reactive factors to the observed cost. The results of a one-way ANOVA revealed a significant main effect of Previous Trial Type, $F(2, 30) = 82.3$, $p < .001$. Post hoc tests showed that all corrected pairwise comparisons differed from one another, with DA-M trials preceded by another DA-M trial being the fastest, those preceded by DP-C trial being intermediate, and those subsequent to a DP-I trial being the slowest (all ps < 0.01). Crucially, however, one should note that even by considering only DA-M trials preceded by another DA-M trial and comparing them to DA-O trials, a robust strategic cost is still obtained, $t(15) = 4.66$, $p < .001$, $\eta^2 = 0.77$.

While the general finding of a strategic cost was fully confirmed in the present experiment, here we also observed that a minor component of the cost measured in the mixed session was due to reactive engagement of the filtering mechanism following a distracter-present trial. Interestingly, not only DP-I trials, but even DP-C trials led to a significant slowing-down on the subsequent DA-M trial. This latter finding is discussed further in a later section.

Experiment 6

With the previous experiments, we provided compelling evidence in favor of a mechanism for the strategic filtering of potential distraction. Specifically, we demonstrated that the filtering mechanism is recruited to deal with probable forthcoming distraction both within and between sensory modalities, in tactile, visuo-tactile, and audio-visual tasks. We claim that this filtering mechanism would be a general component of attentional control. With this experiment (see Figure 6a), we aim to support this claim by showing that strategic filtering occurs in the context of yet another target modality (visual) and, even more important, that it may be evidenced by applying the same logic as in the previous experiments to a well-established attentional task such as the arrow flanker task (e.g., Ridderinkhof et al., 2002).

Consistently with prior literature (Enns & Akhtar, 1989; Eriksen et al., 1985; Ridderinkhof et al., 2002), we measured a significant *distracter interference* effect, with RTs to DP-I trials being slower than those to DP-C trials (mean RTs: 467 ms and 425 ms, respectively), $t(15) = 8.07$, $p < .001$, $\eta^2 = 0.90$. Additionally, participants were more prone to errors when they faced an incongruent, compared to a congruent, distracter, $t(15) = 3.46$, $p < .005$.

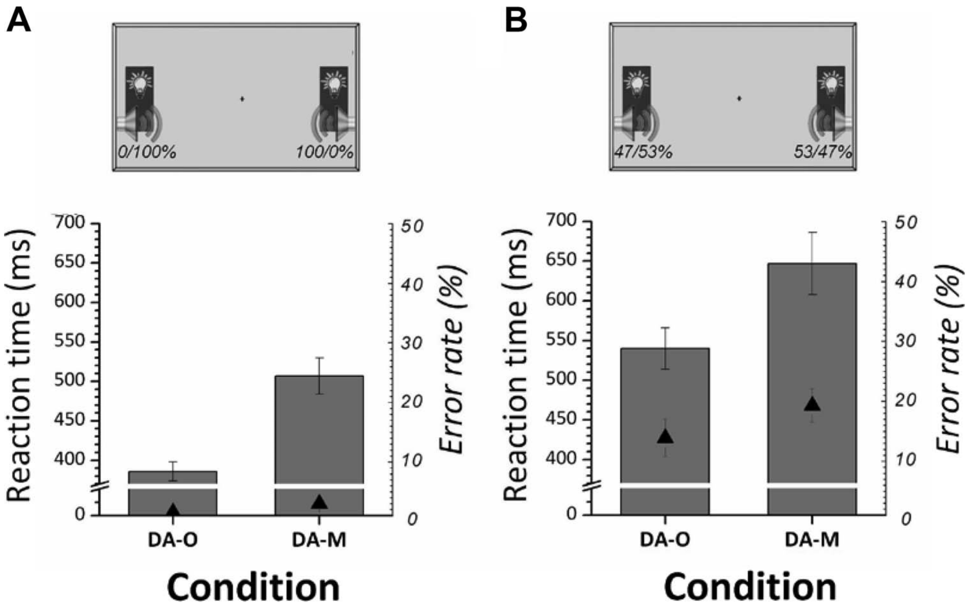

Figure 5. A. Set-up and results for Experiment 5. B. Set-up and results for Experiment 7. The upper part of each panel depicts a schematic representation of the experimental setup, where semitransparent loudspeaker icons represent the position of the occluded loudspeakers and the lamp symbols represent the position of the visual distracters. Lower graphs show RTs (columns, left-side axis) and error rates (triangles, right-side axis) for the two critical distracter-absent conditions: distracter-absent only (DA-O) and distracter-absent mixed (DA-M). Differences ($p < .005$ for all RTs pairs) index the cost of engaging the mechanism for the strategic filtering of potential distraction. Error bars represent standard error. RT = reaction time.

Importantly, we measured a significant slowing-down of responses to distracters-absent trials when they were presented in the "mixed" (i.e., DA-M trials; mean RT: 410 ms), compared to the "pure" (i.e., DA-O trials; mean RT: 380 ms), session, $t(15) = 5.62$, $p < .001$, $\eta^2 = 0.82$ (see Figure 6b). No significant difference in accuracy was found between DA-O and DA-M conditions ($p = .13$). The difference between DA-O and DA-M conditions was also highly significant when measured on inverse efficiency scores, rather than RTs, as the dependent variable, $t(15) = 4.68$, $p < .001$.

The difference in distracter-absent responses between the pure and the mixed block (DA-M minus DA-O) was used as a measure of *strategic cost*, because under our hypothesis it reflects the engagement of an attentional mechanism intended to prevent interference exerted by forthcoming distraction. To provide further support for this view, we ran a correlation analysis between strategic cost and distracter interference, both computed as IE values to employ a more reliable index of performance, as we did for Experiment 1. We found a significant inverse correlation between these factors, $r(14) = -0.57$, $p < .05$ (see Figure 6d), fully replicating the pattern observed in Experiment 1.

Similarly to Experiments 1 and 2, we also analyzed DA-M trials by sorting them according to the preceding trial type. The related ANOVA resulted in a significant main effect of Previous Trial Type, $F(2, 30) = 8.97$, $p < .001$, $\eta^2 = 0.37$, and post hoc tests revealed that DA-M trials preceded by incongruent distracter trials were slower than those preceded by a DP-C ($p < .01$) and by a DA-M ($p < .05$) trial (see Figure 6c). However, differently from what observed in Experiment 2, where the strategic cost was abolished when considering only DA-M trials preceded by another DA-M trial, in the present experiment the strategic cost remained significant even when computed in this more stringent manner, $t(15) = 2.24$, $p < .05$, $\eta^2 = 0.52$. Effect-size values indicate that, while part of the variance is explained by the preceding trial type, a significant amount of overall variance (namely, 52%) is still explained in this experiment by the "session" factor, even after having subtracted out the reactive component of the filtering activation. This pattern of results clearly supports the idea that a distracter filtering mechanism is strategically engaged during the mixed session in Experiment 6.

Experiment 7

In Experiments 1–6, we provided solid evidence for the slowing-down of responses to stimuli from different sensory modalities in the absence of distraction when these stimuli are embedded in a potentially distracting context. We argued that such an impaired performance attests to the recruitment of a resource-demanding mechanism for the strategic filtering of upcoming distraction.

However, one could entertain an alternative interpretation of the results reported thus far. The RT cost in DA-M trials, compared to DA-O trials, could be conceived as a form of strategic response procrastination within the mixed session in order to increase the level of cognitive processing of the given stimuli before response emission, thus contrasting more efficiently the disturbing influence of (potential) distracters and permitting the resolution of potential response conflicts. If this were the

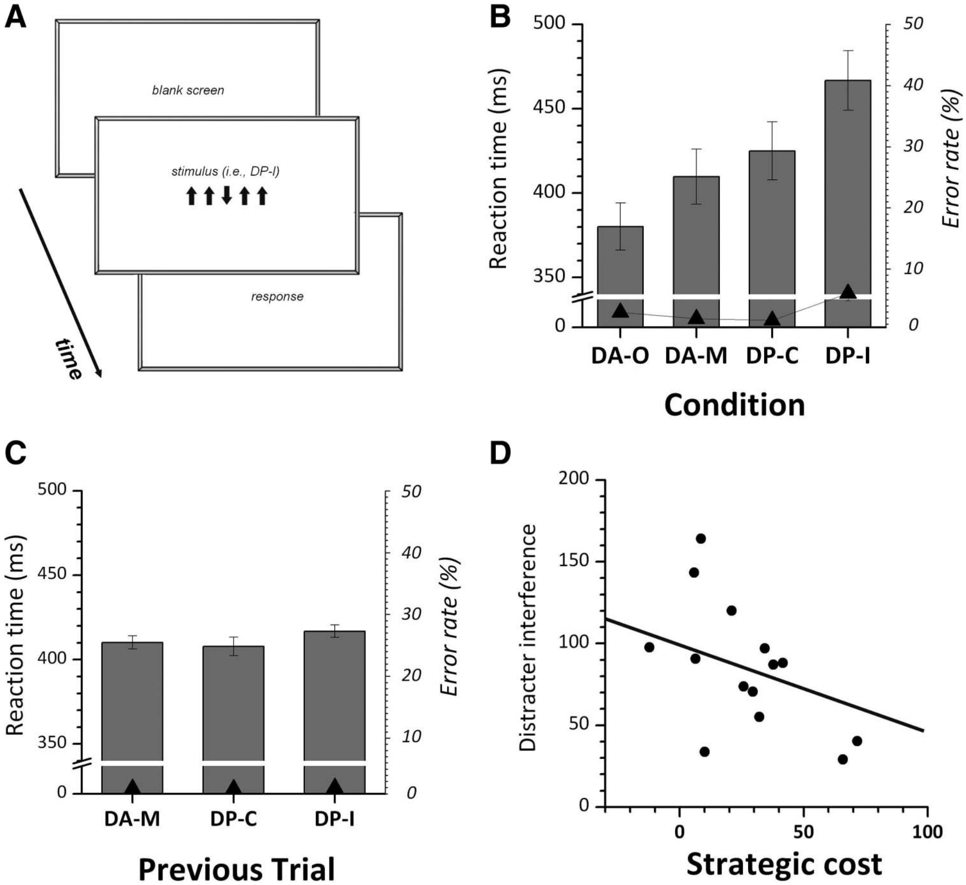

Figure 6. A. Experimental setup of the visual arrow flanker task used in Experiment 6. For display purposes, a distracter-present incongruent (DP-I) trial is shown. In this trial, a central target (downward arrow) is flanked by two incongruent distracters (upward arrows). In DP-C trials, the flanking arrows were oriented the same way as the central target. In distracter-absent trials (DA-O, DA-M), only the central arrow was present. B. Reaction times (RTs; represented by columns, left-side axis) and error rates (represented by triangles, right-side axis) in Experiment 6, separately for each condition: distracter-absent only (DA-O), distracter-absent mixed (DA-M), distracter-present congruent (DP-C), and distracter-present incongruent (DP-I). The difference between DA-M and DA-O (RTs: $p < .001$) is a measure of the strategic cost, while the difference between DP-I and DP-C (RTs: $p < .001$) indexes distracter interference. Error bars represent standard error. C. Reaction times (represented by columns, left-side axis) and error rates (represented by triangles, right-side axis) to DA-M trials in Experiment 6, separated on the basis of the preceding trial type: DA-M, DP-C, and DP-I. DA-M trials following a DP-I trial were the slowest (*p*s < 0.05). D. Dots show individual correlation points between the strategic cost and the distracter interference, as defined in the main text ($p < .05$). The solid line depicts the least-squares fit for the data as calculated by means of a simple linear regression model. All reported values were computed as inverse efficiency (IE) scores.

case, the longer time allotted for stimulus processing in the mixed (relatively to the pure) session should result in more accurate responses for DA-M trials than for DA-O trials—a typical form of speed–accuracy trade-off. A limited increase in accuracy in distracter-absent trials in the mixed session was observed only in Experiment 1 but not in the subsequent experiments, suggesting prima facie that no substantial speed–accuracy trade-off was taking place overall across experiments. However, given that the mean accuracy was very high in both distracter-absent conditions of Experiment 1 (>95%), as well as of all other experiments, the hypothesized increase of accuracy in the mixed condition might have been concealed by a ceiling effect, that is, by very high accuracy scores under both distracter-absent conditions. We then sought to directly test the aforementioned hypothesis by generally replicating our paradigm of Experiment 5 while increasing task difficulty, which was obtained by reducing the perceived spatial separation between left and right auditory stimuli. This manipulation, by increasing task difficulty, was expected to reduce mean performance accuracy, thus allowing the predicted change in accuracy to emerge. If the observed slowing-down of responses in DA-M trials were due to a more cautious response setting adopted strategically throughout the mixed session, then the longer processing time should lead to better performance accuracy in DA-M trials, compared to DA-O trials, in the present experiment. Conversely, if the observed RT cost in DA-M trials were due to the strategic engagement of the postulated filtering mechanism, that should increase the cognitive load and in turn hamper performance globally, leading to longer RTs and reduced accuracy values. Therefore, any *increase* in accuracy for DA-M trials compared to DA-O trials would be compatible with the response procrastination hypothesis, while a *reduction* in accuracy for the same comparison would fully support the filtering hypothesis.

Results showed that mean RTs for DA-O and DA-M trials in Experiment 7 were 540 ms and 640 ms, respectively, $t(15) = 4.02$, $p < .005$, $\eta^2 = 0.72$, replicating the finding of a filtering cost from the previous experiments (see Figure 5b). Responses to DP-C trials were reliably faster than those to DP-I trials (624 ms and 750 ms, respectively), $t(15) = 6.91$, $p < .001$, $\eta^2 = 0.87$. More relevant to the purpose of the present experiment, we observed a significant decrease in accuracy in DA-M trials (80.7%), compared to DA-O trials (86.1%), $t(15) = 3.55$, $p < .01$, $\eta^2 = 0.68$ (see Figure 5b). In addition, accuracy was higher for DP-C trials (89.9%) than DP-I trials (41.2%), where participants appeared to respond more often to the visual distracter, probably because of audio-visual ventriloquism (Bertelson & Aschersleben, 1998).

These findings suggest that participants were not able to use the prolonged delay before response emission in the DA-M (compared to DA-O) condition for improving their performance, as predicted by the response procrastination account. Rather, participants slowed-down their responses and were also more prone to errors in DA-M trials, compared to DA-O trials. We argue that in the DA-M condition participants paid an overall cost in performance, as indexed by both RTs and accuracy data, because they were strategically adopting an attentional setting that caused a reduction of available cognitive resources for the main task, compared to the pure session. Then, these results strongly support the filtering hypothesis.

General Discussion

In the present study we wished to uncover and characterize a putative cognitive mechanism that is recruited in order to prevent interference from irrelevant stimuli in a potentially distracting context. We hypothesized and demonstrated that this mechanism relies on resource-demanding processes and therefore leads to a sizeable performance cost when distraction is likely yet currently absent.

Specifically we showed that the speeded processing of a sensory stimulus in a simple discrimination task is severely slowed-down in a *potentially* distracting context, crucially when distraction does not occur, compared to the discrimination of the exact same stimulus in a session in which the probability of distracters' occurrence is null. Preliminary converging evidence can be found in a prior study in the domain of developmental psychology (Enns & Akhtar, 1989), where a mean RT cost of 32 ms was obtained for younger adults performing distracter-absent trials in pure and mixed blocks. Incidentally, in that study the cost in the mixed condition was even greater in children. This observation supports the existence of a context-sensitive mechanism for the filtering of potential distraction that is present even early during development.

Critically, if one considers only the single target trials where that cost is observed, there are no differences at all (e.g., in terms of sensory stimulation, attentional demands, participants' task) between the two sessions (with potential distracters or without distracters). When one instead considers the global context, one comes to realize that trials with slowed-down responses (DA-M) were embedded in a trial-sequence where most trials contained a concurrent distracter (e.g., in Experiment 1), whereas in the DA-O session distracters never occurred. It appears therefore reasonable to hypothesize that the observed cost is driven by the global context.

The main question then becomes what kind of specific mechanism the brain must engage during the execution a perceptual task in a potentially distracting context. It is likely that its functional role should be related to the effort to optimize resources and performance in the specific task and within the given context. We then argue that, within the context of our simple perceptual task, which is not highly demanding in terms of attentional resources, a mechanism preventing the automatic shifts of attention toward distracters is strategically engaged throughout the potentially distracting session, in order to reduce interference when distraction occurs. This sustained process entails increased activity in monitoring systems, diminishing available resources for target processing and therefore causing the observed slowing-down of responses in DA-M trials.

However, also a different interpretation might account for the observed slowing-down. In mixed blocks, participants might adopt a more cautious attentional setting in order to resolve conflict and prevent distracter-driven responses. This particular setting may be conceived as a strategic shift of response criterion in the mixed session, compared to the pure session, resulting in a form of speed–accuracy trade-off (e.g., Wickelgren, 1977), namely, the adoption of a higher response threshold that would allow deeper and more accurate sensory processing, at the cost of longer RTs (Brown & Heathcote, 2008; Ratcliff, 2002). Accordingly, if the slowing-down we observed in DA-M trials were due to strategic response procrastination, an increase in accuracy should be observed as well in the same condition. In Experiment 7, which was specifically designed to test this hypothesis, we actually measured the reverse pattern, in that participants were both slower and less accurate in distracter-absent trials of the mixed (compared to the pure) session. Thus, our data allow us to reject the response procrastination account and instead fully support the costly filtering hypothesis.

The observed strategic cost is intimately related to the blocking of interference from distracters, when they occur. In fact, the correlation analysis showed that these two measures are inversely correlated: the greater the filtering cost, the lower the actual interference, and vice versa. This result provides strong evidence that the filtering cost reflects activation of a mechanism whose purpose is to filter out distracters and thus fully confirms our interpretation. Interestingly, the interparticipant variability in the amount of the strategic cost might be related to differences in the individual effort and/or ability to activate the strategic filtering mechanism, although it might also depend on the total amount of resources available to the single individual. In particular, the recruitment of a strategic mechanism for attentional control has been related to working memory (WM) capacity, with high-WM-capacity individuals using proactive control and low-WM-capacity individuals relying mainly on reactive processes to deal with incongruent distracters in a Simon task (Gulbinaite & Johnson, 2011).

In principle, the observed slowing-down of responses in DA-M trials, compared to DA-O trials, is not sufficient to guarantee that the filtering mechanism is tonically active throughout the potentially distracting session. Reaction time experiments with conflicting stimuli typically highlight a slowing-down of responses in trials immediately following trials with conflicting stimuli (Verguts, Notebaert, Kunde, & Wühr, 2011). A perhaps analogous increase in response latency is also observed immediately after errors, and it has been termed *post-error slowing* (Botvinick et al., 2001). These effects represent behavioral adjustments due to intertrial contingencies, and they are supposed to rely upon reactive processes. We considered post-error slowing as a possible determinant for the observed cost. The relative analysis in Experiment 1 confirmed the occurrence of post-error slowing but also revealed that this phenomenon does not account for the observed strategic cost. Concerning post-conflict slowing, it is worth noting that, when comparing response times in DA-M trials as a function of the previous trial type, we found that the latter does not modulate the behavioral cost when distracters were highly probable (Experiment 1 and Experiments 3–4). Participants were not reliably slower after incongruent trials compared to congruent or distracter-absent trials. A significant preceding-trial effect was indeed observed in Experiments 5 and 6. However, further analyses showed that the strategic cost in Experiments 5 and 6 was still observed even after subtracting out any reactive component. Globally, the notions of post-error slowing and post-conflict slowing seem inadequate to fully account for our results. These analyses thus confirm the intuition that the mechanism for the filtering of upcoming distraction is engaged on a strategic basis and is tonically sustained along the potentially distracting session.

However, when distraction is expected to occur only in a relative minority of the total trials, a sustained activation of the filtering mechanism might be disadvantageous, as it leads—as we found—to consistent overall behavioral costs. With possible, yet improbable, distraction, the activation of the mechanism for the filtering of distracters might more conveniently rely on reactive, rather than strategic, processes (Morishima, Okuda, & Sakai, 2010). In keeping with that prediction, in Experiment 2, where distraction probability was reduced to 1/3, we found only weak evidence for the activation of the strategic mechanism, as reflected in a sustained filtering cost. This is in line with previous research showing that manipulations of distracters' probability lead to different patterns of interference: the lower the distracters probability, the higher the actual interference they engender, and vice versa (Geyer, Müller, & Krummenacher, 2008). That study varied the probability of distracters across blocks, with 20%, 50%, and 80% of distracter-present trials in different blocks, showing that RTs in distracter-present trials did not differ from RTs in distracter-absent trials in the 80% condition. Under such a high probability of distraction, it is likely that a filtering mechanism was fully operating at all times to prevent interference, but the cost resulting from its engagement cannot be assessed because a pure distracter-absent session was not included in their experimental design.

Moreover, a previous-trial analysis performed by Geyer et al. (2008) revealed that distracter interference was reduced in trials immediately subsequent to a distracter-present trial, compared to trials following a distracter-absent trial. Interestingly, this dependence of RTs upon events in the preceding trial was much higher under low distracters probability, and it was largely reduced when distracters were 80% present. This is quite reminiscent of our findings in Experiments 1 and 2. While in Experiment 1 (with high probability of distraction) the type of the preceding trial did not reliably affect performance in the next DA-M trial, in Experiment 2 (with low probability of distraction) a selective slowing of DA-M responses after incongruent-distracter trials was observed. This finding raises the possibility that the occurrence of a highly distracting event (i.e., the incongruent distracter-present trial) would act as a trigger signal in preparation for the immediately upcoming trial, inducing the participant to dynamically reactivate the distracter filtering process. This is also in line with the idea that observers enhance their on-line control over distracter interference in a certain trial as a result of having encountered a distracter in the preceding trial (Geyer et al., 2008).

In Experiment 1 we also performed a sequence analysis in order to examine (a) whether session order impacted performance and (b) whether there was a carryover of the strategic settings in the initial part of the pure session in those participants who encountered it after the mixed session. Coherently with previous studies (Müller, Geyer, Zehetleitner, & Krummenacher, 2009), we found a robust practice effect, indicating that participants were overall slower in the first pure session compared to the same session performed as the second one. We also observed that the first mini-block in each session was slower than the second one. This latter result might reflect some form of within-session task practice, and it is not due to carryover effects. In fact, carryover effects should have been observed only in participants who performed the pure session after the mixed one, but our data show that the interaction between *Order* and *Mini-Block* was very far from significance ($p = .92$).

Contextual circumstances may well play a widespread role in modulating attentional settings: For example, previous experience can lead to the sustained suppression of irrelevant stimuli by means of the prolonged activation of distracter suppression processes (Dixon, Ruppet, Pratt, & De Rosa, 2009). The mechanism for the filtering of potential distraction we describe here then appears well characterized as a context-sensitive process, being permeable to different modulations depending on the given circumstances. A context where distraction is likely leads to the strategic recruitment of the filtering mechanism, while in contexts where distraction is relatively infrequent the mechanism is preferentially engaged through reactive dynamics.

The aforementioned interpretation also fits well with two well-known phenomena: *post-error reduction of interference* (Danielmeier & Ullsperger, 2011; Ridderinkhof et al., 2002) and *pre-error speeding* (Eichele, Juvodden, Ullsperger, & Eichele, 2010). Post-error reduction of interference was originally described using both a flanker task (Ridderinkhof et al., 2002) and a Simon task (Ridderinkhof, 2002) and consists in a reduced cost caused by incongruent distracters after an error trial. Such effect is thought to depend on cognitive control (King, Korb, von Cramon, & Ullsperger, 2010), and here we claim that a reactive engagement of the filtering mechanism following an error provides a highly compatible account of the results. In addition, it has been recently observed that, in a modified flanker task, participants' responses become increasingly faster over the five trials before an error is committed (Eichele et al., 2010). In agreement with our hypothesis, this progressive speeding observed prior to an error might be indicative of a gradually weakened engagement of the filtering mechanism. That would release cognitive load, leading to faster responses to targets, until the filtering mechanism is so feeble that the occurrence of a distracter causes a wrong response.

Having shown that in potentially distracting contexts a strategic mechanism is engaged to block forthcoming distraction, now an intriguing question regards which characteristic(s) of the distracters this mechanism is actually intended to suppress. A distracter can interfere with the target discrimination task at different levels. When target and distracting stimuli are located in close spatial vicinity, and the distracter is incongruent in terms of elevation, a phenomenon of target mislocalization might occur. In a visuo-tactile task similar to the one we adopted for our experiments (Experiments 1–4), it has previously been shown that a sort of ventriloquism effect (capture of the perceived position of the tactile stimulus by the visual distracter) might partly explain the resulting interference (Spence et al., 2004). Moreover, in visual brain areas, evoked responses to a distracter from the same or another sensory modality relative to the target show an enhancement when distracter and target are in the same, compared to different, spatial location (Ciaramitaro, Bucaras, & Boynton, 2007). Given the above evidence, the strategic mechanism might serve to prevent the perceptual integration of the two stimuli and thus reflect the effort to impede that the location of the visual distracter captures the location of the tactile target. Experiment 3 tested this possibility and results clearly showed that a strategic filtering mechanism is active even when tactile targets and visual distracters are placed in different and distant spatial locations. That finding challenges the hypothesis that the filtering mechanism is primarily aimed to prevent a visuo-tactile ventriloquism effect.

An event-related potentials study has shown that the crossmodal congruency effect reflects a form of response-conflict interference, that is, a competition in incongruent conditions between responses instantiated by target and distracter (B. Forster & Pavone, 2008). Based on that evidence, the strategic filtering mechanism might primarily operate to disable the distracter-driven behavioral response. Recent research has provided substantial evidence for a control mechanism aimed to prevent and suppress response tendencies, a phenomenon termed *proactive inhibition* (Jaffard, Benraiss, Longcamp, Velay, & Boulinguez, 2007).

The latter mechanism critically involves medial prefrontal cortex (Boulinguez, Ballanger, Granjon, & Benraiss, 2009; Jaffard et al., 2008) and exerts a modulation over motor regions, including primary motor cortex, supplementary motor cortex, and putamen in humans (Jaffard et al., 2008), with converging evidence for the supplementary motor area in the macaque (Wardak, 2011). Proactive inhibition can be sustained during task execution, starting even before any stimulus is presented (Cai et al., 2011). The behavioral signature of such proactive inhibition is the slowing-down of target responses when target trials are intermixed with nontargets, compared to a control condition in which only target stimuli are presented (Jaffard et al., 2008). This effect is strongly reminiscent of our own findings; however, it is important to note that a key requirement for proactive inhibition of motor responses is that a sensory stimulus should tend to evoke by itself a specific motor response. On the contrary, we showed that in our paradigm the strategic filtering mechanism is engaged even when the distracters are entirely task irrelevant, and they are not associated to any behavioral response code, as it was the case in Experiment 3 Condition C. Although the notion of proactive inhibition might account for the behavioral cost observed in Experiments 1, 2, and 3 (Condition B), it clearly fails to explain results from Experiment 3 (Condition C), suggesting that the mechanism of strategic filtering uncovered here is primarily related to attentional, rather than motor, processes.

More specifically, results from Condition C of Experiment 3 suggest that the filtering mechanism is still active when the distracter is a flashing light shown at fixation. Under such circumstances, the only way in which the distracter can conceivably interfere with the main task is via a bottom-up attentional capture mechanism. At present, it is still hotly debated whether attentional capture is susceptible to top-down modulations: some studies have found no evidence in that direction (e.g., Koelewijn, Bronkhorst, & Theeuwes, 2009); however, other recent research has reported some form of control over the exogenous capture of attention (Chisholm, Hickey, Theuwees, & Kingstone, 2010; Eimer & Kiss, 2008). Findings from Condition C of Experiment 3 could nicely fit with the idea that a strategic setting of cognitive control is adopted for preventing the exogenous capture of attention by a salient, yet irrelevant, distracter, in turn leading to an appreciable behavioral cost when the distracter is absent.

In Experiments 1–4 we disclose and characterize a mechanism for the strategic filtering of upcoming distraction in a task with visual or tactile distracters and tactile targets. Since these two modalities are closely related (Macaluso et al., 2000, 2002), the observed results might be specific for visuo-tactile stimulus pairs. We ruled out this possibility by fully confirming the finding of a strategic cost in Experiments 5 and 7, where target stimuli were auditory rather than tactile. Incongruent visual distracters yielded greater interference in the auditory lateralization task of Experiments 5 and 7, compared to the tactile elevation task of Experiments 1–4. Parallel to this more robust distracter interference effect, in Experiments 5 and 7 also the measured strategic cost was dramatically strong, likely because of the increased filtering demands determined by highly interfering visual distracters.

The claim of generality for the strategic filtering mechanism and its independence of the sensory modality and task procedures are further supported by Experiment 6. There, we applied the very same logic to a completely different paradigm (i.e., an arrow flanker task) and fully replicated findings from the preceding experiments. Remarkably, we provided further evidence for the close relationship between the strategic cost and the distracter interference, by showing once more with a correlation analysis that these two measures are inversely correlated.

The remarkably coherent pattern of results from all experiments combined fully supports our claim of a supramodal mechanism for the strategic filtering of distraction and provides compelling evidence that it represents a general and fundamental component of attentional control. Compatible evidence has been recently reported in a study by Wendt, Luna-Rodriguez, and Jacobsen (2012), where they showed that context-dependent modulations of stimulus attributes (either spatial position or color) attest to perceptual filtering of distracter's features.

A neurophysiological observation obtained with fMRI potentially related to the strategic filtering mechanism reported here is the increased preparatory activity (i.e., brain activity measured prior to stimulus onset in visual cortex) that is typically observed when interference from distracters is likely, rather than when it is unlikely (Serences et al., 2004). Preparatory BOLD activity could reflect increased anticipatory inhibition of neural responses in brain areas representing distracters; thus, its enhancement might be a sign of increase in attentional control settings for distracters suppression. In the same study (Serences et al., 2004), a null behavioral effect of distracters' probability is found on distracter-absent trials. Although that might appear to be in sharp contrast with our findings, in Serences et al.'s (2004) study effects were assessed only in terms of changes in accuracy (whereas RTs were not analyzed), and we also do not observe changes in accuracy (except than in Experiment 7), whereas the cost we measure mostly emerges in response times. Of course other differences in paradigm and methodology could also account for the apparent discrepancy between results from their study and the present one.

In a recent visuo-acoustic study (Weissman, Warner, & Woldorff, 2009), longer RTs were coupled with a reduction of activity in sensory-specific target-related areas as well as with an increase of activity in sensory-specific distracter-related areas and in frontal regions related to conflict representation and monitoring, including the anterior cingulate cortex, thus suggesting a potential failure in distracter suppression which in turn leads to longer RTs. Although this is a merely speculative argument, it is tempting to hypothesize that the strategic filtering mechanism that we propose could rely on context-sensitive monitoring mechanisms involved in the control of spatial attention. The attentional control network could then determine the desired top-down modulation from frontal onto parietal and posterior sensory areas (Asplund, Todd, Snyder, & Marois, 2010; Corbetta & Shulman, 2002; Esterman, Chiu, Tamber-Rosenau, & Yantis, 2009; Greenberg, Esterman, Wilson, Serences, & Yantis, 2010; Szczepanski, Konen, & Kastner, 2010), resulting in an inhibitory modulation of the distracters' representation. The increased attentional load associated with activation of such distracters' suppression mechanism (Kelley & Lavie, 2011), however, might be costly for target processing, leading to longer RTs.

Our data support the idea that the filtering mechanism acts at a supramodal level. We measured the strategic cost in visuo-tactile (Experiments 1–3) and visuo-acoustic (Experiments 5 and 7) conditions and also within the tactile (Experiment 4) and the visual (Experiment 6) modality. Interestingly, it has been documented that, in an audio-visual selective attention task, the neural representation of visual distracters are susceptible of different degrees of attenuation depending on the sensory modality of the target (Ciaramitaro et al., 2007). However, as shown by the results from our experiments, the cost ensuing from the strategic activation of distracter-filtering mechanisms occurs both within and between sensory modalities; thus, it is likely to reflect supramodal attentional (and not sensory-specific) processes. Even if our data do not permit one to positively determine that the *same* filtering mechanism is operating within and between modalities—an issue that we plan to address with future research—the present results are fully compatible with the notion that the filtering mechanism is supramodal in nature, and they suggest that it is likely a general mechanism of attentional control.

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