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# The cognitive locus of distraction by acoustic novelty in the cross-modal oddball task

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**Abstract**

Unexpected stimuli are often able to distract us away from a task at hand. The present study seeks to explore some of the mechanisms underpinning this phenomenon. Studies of involuntary attention capture using the oddball task have repeatedly shown that infrequent auditory changes in a series of otherwise repeating sounds trigger an automatic response to the novel or deviant stimulus. This attention capture has been shown to disrupt participants' behavioral performance in a primary task, even when distractors and targets are asynchronous and presented in distinct sensory modalities. This distraction effect is generally considered as a by-product of the capture of attention by the novel or deviant stimulus, but the exact cognitive locus of this effect and the interplay between attention capture and target processing has remained relatively ignored. The present study reports three behavioral experiments using a cross-modal oddball task to examine whether the distraction triggered by auditory novelty affects the processing of the target stimuli. Our results showed that variations in the demands placed on the visual analysis (Experiment 1) or categorical processing of the target (Experiment 2) did not impact on distraction. Instead, the cancellation of distraction by the presentation of an irrelevant visual stimulus presented immediately before the visual target (Experiment 3) suggested

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that distraction originated in the shifts of attention occurring between attention capture and the onset of the target processing. Possible accounts of these shifts are discussed.


*Keywords:* Novelty detection; Attention capture; Oddball task; Auditory distraction; Electrophysiology

## 1. Introduction

While efficient everyday functioning often requires the ability to selectively attend to some stimuli, it is equally important to maintain a certain degree of distractibility by task-irrelevant but otherwise potentially relevant events. Detecting an event violating the regularity of previous stimuli can for example warn of an imminent danger (e.g., an unexpected change in an aircraft engine's noise may signal a malfunction). In some circumstances, the propensity of transient environmental changes to capture our attention can have dramatic effects. For example, a report by the US National Transportation Safety Board examining 37 major accidents of US carriers from 1978 to 1990 revealed that nearly half these accidents involved lapses of attention associated with interruptions, distractions, or preoccupation with one task to the exclusion of another (Dornheim, 2000).

The distractive value of task-extraneous sound has been demonstrated in a variety of settings. For example, past research has shown that continuous irrelevant changing sounds can impair, for example, order memory (e.g., Jones, Alford, Bridges, Tremblay, & Macken, 1999; Jones, Farrand, Stuart, & Morris, 1995; Jones & Macken, 1993; Jones, Madden, & Miles, 1992; Tremblay, Macken, & Jones, 2001) and various office tasks (Banbury & Berry, 1997, 1998). Single auditory stimuli can also disrupt cognition by capturing attention away from ongoing cognitive processes, as shown in serial memory (Hughes, Vachon, & Jones, 2005; Lange, 2005), arithmetic (Woodhead, 1964), visual comparison (Woodhead, 1959), or motor pursuit tasks (Jones & Broadbent, 1991; May & Rice, 1971).

The present study examines the distraction occurring when stimuli in our environment deviate from the events expected by our cognitive system. As will become clear in the next pages, such distraction relates to core aspects of cognition, such as its tendency to build mental models of events to help deal with upcoming stimuli, and its propensity to orient attention towards events violating such models. The present study sought to examine the distraction yielded by such orientation responses. Specifically, it investigated whether attention-grabbing distractors impair ongoing cognitive performance due to competition for attentional resources or due to dynamic shifts of attention to and from distractors.

It is well established that infrequent auditory changes (so called oddball stimuli) in a train of repetitive stimuli capture attention in an obligatory fashion. From an electrophysiological standpoint, the brain response to auditory novelty is characterized by three specific responses, even when novel sounds are unrelated to the participants' task. These responses, referred to as the 'distraction potential' (Escera & Corral, 2003) are: the mismatch negativity (MMN) and the enhancement of N1 generators when the distracter deviates a great deal from the repetitive background (Alho et al., 1998), P3a (sometimes referred to as novelty P3; see Friedman, Cycowicz, & Gaeta, 2001, for a review) and the re-orientation negativity (RON; e.g., Schröger & Wolff, 1998b). The mismatch negativity reflects the pre-attentive detection of a change (or even the illusion of a change, see Stekelenburg, Vroomen, & deGelder, 2004) in the auditory context. The underlying mechanism eliciting this response is a comparison between a memory trace of the acoustic regularities of past sound events and the current auditory signal (see Näätänen & Winkler, 1999; Picton, Alain, Otten, Ritter, & Achim, 2000, for reviews). The output of this detection system is an attentional interrupt hypothesized to involve frontal activations (Opitz, Rinne, Mecklinger, von Cramon, & Schröger, 2002) and resulting in the involuntary orientation of attention towards a novel sound, marked by the P3a response (Friedman et al., 2001; Grillon, Courchesne, Ameli, Geyer, & Braff, 1990; Woods, 1992). When participants must perform a primary task, a later deflection is also observed and interpreted as the re-orientation of attention towards that task (Berti & Schröger, 2001; Berti, Roeber, & Schröger, 2004; Escera, Yago, & Alho, 2001; Schröger & Wolff, 1998a).

While most studies on auditory attention capture focus on the sound-related electrophysiological responses, some researchers have used paradigms in which the impact of this capture can be measured behaviorally from the participant's performance in an attention-demanding task. For example, Schröger (1996) found that MMN-eliciting deviants presented among standards to the unattended ear delayed participants' response to auditory targets in the other ear. In a slightly different task (Schröger & Wolff, 1998a, 1998b), participants had to discriminate between long and short sounds irrespective of their frequency (a repeated- or *standard*-frequency was presented in most trials but replaced by a *deviant* on rare occasions). Even though frequency was irrelevant to the participants' discrimination task and was to be ignored, response latencies in the primary task were significantly longer for frequency deviants relative to frequency standards. Distraction in this paradigm was shown to be independent of the stimulus-onset asynchrony (Roeber, Berti, & Schröger, 2003) but to decrease when participants performed the discrimination task while concurrently holding a memory load (Berti & Schröger, 2003).

A large proportion of previous oddball studies have used the so called one-channel paradigm in which targets and deviants are presented auditorily, usually as distinct features of the same auditory object (e.g., frequency and duration). Remarkably, however, target and irrelevant stimuli do not need to be presented at the same time or in the same sensory modality for behavioral distraction to occur. This is important because it highlights the amodal nature of this phenomenon (that is, distraction does not merely occur due to the orientation of attention towards the same attended sensory modality as the target). Indeed, performance in a *visual* discrimination task is also affected by *auditory* deviants or novels (two-channel paradigm). This has been repeatedly demonstrated in studies using the cross-modal oddball task (e.g., Andrés, Parmentier, & Escera, 2006; Escera, Alho, Winkler, & Näätänen, 1998; Escera, Corral, & Yago, 2002). In this task, participants categorize visual digits, presented in sequence, as odd or even. Each digit is preceded by a task-irrelevant sound that participants are instructed to ignore. This sound is repeated on

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most trials (standard) but is replaced by a deviant or a novel on rare occasions (e.g., 20% of trials). In addition to the distraction potential elicited by novel or deviant sounds, response latencies in the categorization task are consistently longer for digits preceded by deviants or novels compared to standards.

While the oddball paradigm is one of the most widely used methods to study the neurophysiology of attention, there is currently no cognitive analysis of the distraction induced by novel stimuli. Of particular relevance in the present study, the cognitive locus of the effect of distraction observed in the cross-modal oddball task remains unexplored. Past studies have usually implicitly considered that the electrophysiological response to a novel is responsible for the behavioral distraction in a subsequent and unrelated primary task. It is however not obvious how exactly the capture of attention by a novel sound should interplay with the processing of an unrelated and attended visual event. Why do participants take longer to report that, for example, "8" is an even number when it is preceded by a novel sound compared to a standard? Up to date, it was unclear why the processing of a visual digit should be affected by the presentation of a sound that is (1) irrelevant to the participant's task, (2) presented in a different modality, (3) presented at a different time; and (4) that does not, arguably, afford any response or prime any mental representation that may possibly relate to the digit processing. This is the issue addressed in this study.

Several positions can be entertained with respect to the potential ways in which behavioral performance in a primary visual task may be affected by auditory novels: through a competition for attentional resources (Johnston & Heinz, 1978; Kahneman, 1973) between the processing of the target and the pre-attentive processing of the novel sound, and/or through an attention bottleneck (Broadbent, 1958; Pashler, Johnston, & Ruthruff, 2001; Welford, 1967) delaying the onset of the processing of the target until attention switches from the sound analysis back to the visual task. Under the first hypothesis, the response to the visual target may be delayed because its processing is slowed by a relative depletion of attention resources. A previous study showing that visual ERPs (extraestriate N1) were attenuated following a deviant tone compared to a standard one (Alho, Escera, Díaz, Yago, & Serra, 1997) would support this hypothesis. Under the second hypothesis, however, responding to the visual target following a novel sound may be delayed because time is required for attention to shift to the novel sound, engage in its analysis, and return towards the primary task. The processing of the visual target itself would not be affected; its onset would. The two hypotheses predict different cognitive loci for the distraction observed in the cross-modal oddball task in which participants categorize visual digits (e.g., Escera, Alho, Schröger, & Winkler, 2000; Escera & Corral, 2003). The resource competition hypothesis places the locus of distraction at the digit processing stage of the task. The bottleneck hypothesis predicts that the processing of the digit is not the locus of distraction but that the shifts of attention to the novel and then back to the digit are.

In Experiments 1 and 2, we tested the hypothesis that distraction in the cross-modal oddball task may reflect the depletion of attention resources available to process the visual target when attention is captured by an irrelevant novel sound. Reporting that a digit is odd or even involves a number of processing steps, any of which potentially sensitive to distraction. In our effort to identify the possible cognitive locus of distraction among these processing steps, we started by dividing the processing of the visual digit into two broad categories of processes: (1) the perceptual analysis of the visual input, from the registration of a pattern of light on the retina to the identification of the stimulus as a digit; and (2) the categorization and response selection. In Experiment 1, we manipulated the demands placed on the visual analysis stage and examined whether perceptually degraded visual stimuli would amplify the distraction induced by novel sounds. In Experiment 2, we applied the same logic to the manipulation of the categorization difficulty. In both cases, the rationale was the following: If the distraction entailed by the involuntary capture of attention by auditory novels results from the impaired processing of the target stimulus, then making this processing more demanding should amplify distraction.

## 2. Experiment 1

### 2.1. Method

#### 2.1.1. Participants

Twenty (14 females) undergraduates from the University of Plymouth took part in this experiment in exchange for a small honorarium. Participants were between 18 and 37 years of age (M = 22.8, SD = 4.47). All participants reported correct or corrected-to-normal vision and normal hearing.

#### 2.1.2. Stimuli, design and procedure

Participants were presented with 4 blocks of 424 trials each. In each trial, participants had to categorize a digit (1–8) as odd or even. A fixation box was visible at the centre of the screen throughout the task. The digits were presented in random order (different for every participant), but with equal probabilities across the task, at the centre of the presentation box, sustaining a viewing angle of approximately 2.6° (participants were seated at approximately 50 cm of the screen). Each digit was presented for 200 ms.

In all trials, a 200 ms sound was presented 300 ms before the onset of the visual stimulus. Participants were told that the sound was a distracter and that they should ignore it. From the onset of a digit, participants had 1000 ms to respond. Following a further 100 ms, the next trial was automatically initiated. Participants used the keys Z and X on the computer keyboard to respond using two fingers of their dominant hand. The mapping between the response keys and the odd/even responses was counterbalanced across participants.

Two sound conditions were compared within each block. In the *standard condition* (90% of trials), the sound was a 600 Hz sinewave tone of 200 ms duration (10 ms of rise/fall times), hereafter referred to as the *standard*. In the *novel condition* (10% of trials), we used 60 different environmental sounds adapted from Escera, Yago, Corral, Corbera, and Nuñez (2003), hereafter referred to as *novels*. All novels had a 200 ms duration (including 10 ms rise/fall times), were digitally recorded, and

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low-pass filtered at 10,000 Hz. Each novel sound was only used a maximum of three times across the experiment. Novel sounds were always preceded by at least one standard trial. All sounds were normalized and presented binaurally through headphones at approximately 75 dB. In each block, the first 24 trials, which only contained standards, were treated as warm-up trials and were not included in the data analysis. Across the 1600 test trials, 16 novel sounds were used within every successive group of 160 trials (proportion of novels = .1) to ensure a relatively even, yet unpredictable, distribution of novels across trials. The order of presentation of the standard and novel trials was otherwise random and different for every participant.

Two conditions were compared with regard to the characteristics of the visual digits. In the *control condition*, all digits were presented in black against a white background. The *visual interference* condition differed from the control condition insofar as the digits were degraded in two ways using the Adobe Photoshop graphics editing software: their transparency was set to 50% and a visual mask made of static visual noise (a 400% Gaussian noise) was added across the presentation box (see Fig. 1). In both conditions, the digit sustained an angle of about 2.6° (participants sat at approximately 50 cm from the screen). Two blocks of trials were presented in alternation in each condition and presented. Ten participants performed these blocks in an ABAB arrangement while the other 10 performed it in a BABA arrangement.

Participants were tested individually in a quiet room. They were instructed to focus on a fixation box at the centre of the computer screen and to categorize each digit as odd or even by pressing the corresponding response keys while ignoring the sounds. Instructions emphasized the need for both speed and accuracy.

### 2.2. Results

In all experiments reported in this study, both response latencies for correct responses and accuracy were analyzed. Attention capture in the cross-modal oddball

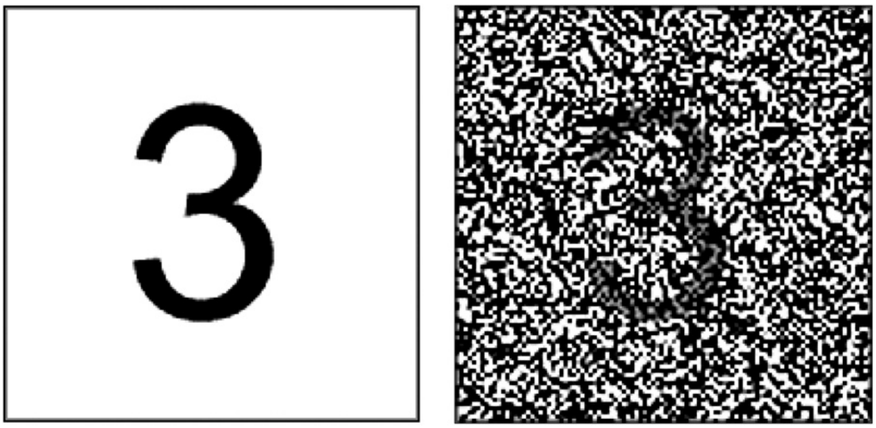


Fig. 1. Illustration of the interference manipulation used in Experiment 1. Visually degraded stimuli (right panel) were set to a transparency of 50% and accompanied by static visual noise.

task is typically evidenced in RTs (e.g., Escera et al., 1998) but effects are also occasionally observed in the accuracy data (Escera et al., 2001). While, to anticipate, RTs proved more informative, accuracy data are reported for completeness.

### *2.2.1. Response latencies*

Response latencies for correct responses were analyzed in a 2 (control versus interference) × 2 (standard versus novel) ANOVA for repeated measures. Participants were significantly slower in the interference condition than in the control condition, $F(1,19) = 412.854$, $\text{MSE} = 161.158$, $p < .001$, $\eta_p^2 = .956$. Novel sounds yielded a significant effect of distraction, as evidenced by longer RTs for novels than standards, $F(1,19) = 22.539$, $\text{MSE} = 231.230$, $p < .001$, $\eta_p^2 = .543$. Most importantly, however, visual interference did not increase distraction relative to the control condition, $F(1,19) < 1$, $\text{MSE} = 79.269$, $p = .376$, $\eta_p^2 = .041$ (see Fig. 2).

### *2.2.2. Accuracy*

The proportion of correct responses was high overall ($M = .927$, $SD = 0.038$). A 2 (control versus interference) × 2 (standard versus novel) ANOVA for repeated measures revealed that accuracy was unaffected by the presence of visual interference, $F(1,19) = 2.576$, $\text{MSE} = .000851$, $p = .125$, $\eta_p^2 = .119$, or by the type of sound, $F(1,19) < 1$, $\text{MSE} = .000446$, $p = .357$, $\eta_p^2 = .045$. Finally, no interaction was observed between the visual condition and the type of sound, $F(1,19) = 2.003$, $\text{MSE} = .000299$, $p = .173$, $\eta_p^2 = .095$.

## *2.3. Discussion*

The pattern of results from Experiment 1 is clear-cut. Participants exhibited longer response latencies following a novel irrelevant sound than a standard irrelevant sound, in line with previous research (e.g., Escera et al., 2000; Escera & Corral, 2003). The original finding is that this distraction appeared to be independent from the visual analysis of the target stimulus. The manipulation of the digits' visual appearance did make the visual analysis of the stimuli more demanding, as demonstrated by its significant and statistically large effect on response latencies, but distraction remained constant.

The results of the Experiment 1 are compatible with two hypotheses: that distraction in the cross-modal oddball task is independent of the digit processing, or that it is only independent from its visual analysis but possibly related to later processing stages (the categorization of the digit, or the preparation and execution of the response). Experiment 2 sought to examine this second hypothesis by manipulating the demands of the categorization and response selection/execution stage of processing while keeping the demand placed on the visual analysis constant.

In Experiment 2, we manipulated the difficulty of the categorization and response selection/manipulation by comparing two task rules. Participants were required to categorize each visual digit into two well practiced categories (odd/even) or into four arbitrary and unfamiliar categories (see Shimamura, 1994, for evidence of the impact

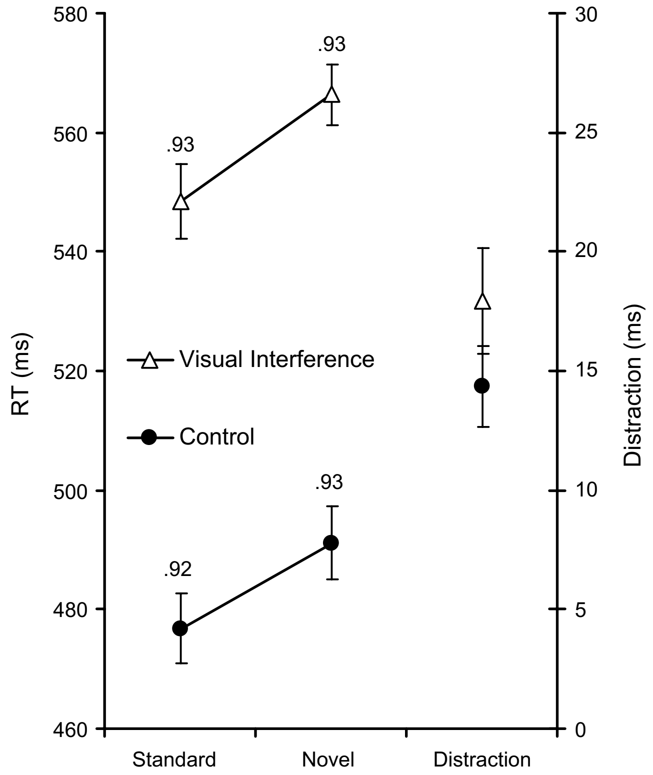


Fig. 2. Performance in Experiment 1. Data points represent the response latencies in the control and visual interference conditions, for the standard and novel sound conditions. The proportion of correct responses for each condition is reported beside each data point. Distraction, defined as $RT_{novel} - RT_{standard}$, is depicted on the right of the figure (secondary *Y*-axis). Error bars represent one standard error of the mean.

of the number of categories on discrimination speed). Under the hypothesis that the locus of distraction in the cross-modal oddball task is the categorization of the digit and/or the output of a response, making this broad stage of processing more demanding should amplify distraction.

## 3. Experiment 2

### 3.1. Method

#### 3.1.1. Participants

Twenty (14 females) undergraduates from the University of Plymouth took part in this experiment in exchange for a small honorarium. Participants were aged between 18 and 39 (M = 21.3, SD = 5.99). All participants reported correct or corrected-to-normal vision and normal hearing. None of the participants had taken part in Experiment 1.

#### 3.1.2. Stimuli, design and procedure

Participants were presented with 4 blocks of 424 trials each. In each trial, the task was as described in the control condition of Experiment 1 (that is, digits were presented without any visual degradation). In addition to the standard and novel conditions as described in Experiment 1, Experiment 2 compared two types of digit categorization. In the *2-categories condition*, participants were required to categorize each digit as odd or even (using the Z and X response keys). In the 4-categories condition, participants were required to categorize each digit into one of four possible categories: Participants pressed the V key if the digit was either 1 or 2, the B key if the digit was either 3 or 4, the N key if is was either 5 or 6, and the M key if it was either 7 or 8. Two blocks of trials were presented in each condition, presented in alternation. Ten participants performed the category conditions in an ABAB arrangement while a BABA arrangement was used for the remaining participants. All other aspects of the experiment were as described in Experiment 1.

### 3.2. Results

#### 3.2.1. Response latencies

Response latencies for correct responses were analyzed in a 2 (control versus interference) × 2 (standard versus novel) ANOVA for repeated measures. The 4-categories condition yielded significantly longer RTs than the 2-categories condition, $F(1,19) = 74.782$, $\text{MSE} = 4166.083$, $p < .001$, $\eta_p^2 = .797$, confirming the relatively demanding nature of the 4-categories condition. A significant effect of distraction was observed, as indicated by longer RTs in the novel condition relative to the standard condition, $F(1,19) = 31.396$, $\text{MSE} = 225.731$, $p < .001$, $\eta_p^2 = .623$. However, as visible in Fig. 3, distraction did not increase with categorization difficulty, $F(1,19) = 3.080$, $\text{MSE} = 166.533$, $p = .095$, $\eta_p^2 = .140$. In fact, numerically, it decreased.

#### 3.2.2. Accuracy

The proportion of correct responses was analyzed in a 2 (2-versus 4-categories) × 2 (standard versus novel) ANOVA for repeated measures. Performance was significantly lower in the 4-categories ($M = .802$, SD = .106) than in the 2-categories ($M = .882$, SD = .070) condition, $F(1,19) = 7.454$, $\text{MSE} = .0173$, $p < .05$, $\eta_p^2 = .282$. Accuracy was not affected by the type of sound, $F(1,19) = 2.107$, $\text{MSE} = .001002$, $p = .163$, $\eta_p^2 = .100$. Finally, there was no interaction between these conditions, $F(1,19) < 1$, $\text{MSE} = .000838$, $p = .606$, $\eta_p^2 = .014$.

### 3.3. Discussion

As in Experiment 1, novel irrelevant sounds produced a robust slowing of responses in the visual categorization task. The critical finding, however, is that this

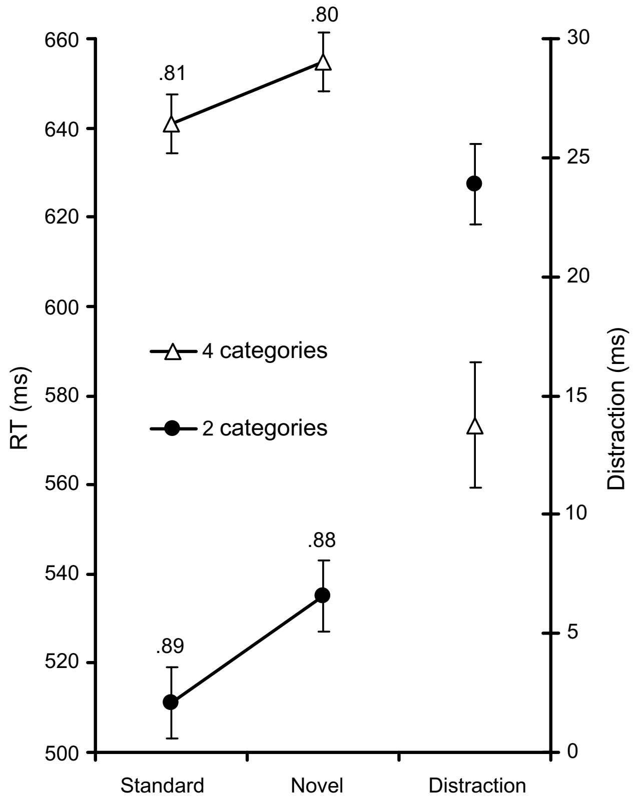


Fig. 3. Performance in Experiment 2. Data points represent the response latencies in the 2- and 4-categories conditions, for the standard and novel sound conditions. The proportion of correct responses for each condition is reported beside each data point. Distraction, defined as $RT_{novel} - RT_{standard}$, is depicted on the right of the figure (secondary *Y*-axis). Error bars represent one standard error of the mean.

distraction effect was not augmented by a nonetheless statistically large and significant effect of the categorization manipulation.

Interestingly, the more difficult categorization appeared to decrease distraction rather than increase it. This is in line with the suggestion that a working memory load can reduce distraction in auditory oddball tasks (Berti & Schröger, 2003). These authors have indeed reported that participants are slower to categorize the duration of auditory stimuli when these stimuli were frequency deviants, but that this effect was reduced when participants had to hold their response in working memory until the onset of the next stimulus. In our 4-categories condition, the rules of the task are arbitrary and one's subjective experience while performing the task is that of continuously refreshing the definition of the categories in memory while performing the task. Odd and even categories are, in contrast, over-learned categories. In that sense, the arbitrary task rules may be regarded as a memory load. Using a liberal (one-tailed) statistic, distraction (RTs) is actually significantly reduced under the 4-categories compared to the 2-categories condition, $t(19) = 2.117$, $p = .048$.

The above result is worth commenting further, for it illustrates the apparent discrepancy between two lines of research concerned with the effect of a working memory load on distraction. On the one hand, Lavie and colleagues (e.g., De Fockert & Lavie, 2001; De Fockert, Rees, Frith, & Lavie, 2001; Lavie, 2005) propose that distraction increases under a working memory load. On the other hand, Berti and Schröger (2003) argue that a working memory load decreases distraction (based on behavioral as well as electrophysiological data), a contention with which our data are compatible. At first sight, the above lines of research appear to be contradictory. While there is currently no systematic empirical test of this issue, one may argue that the methodology used by Lavie and colleagues differs from that used in the oddball paradigm in a potentially critical manner. Indeed, the studies by Lavie and colleagues require participants to make a speeded response to a target presented simultaneously with, and in the same modality as, a distracter stimulus (e.g., categorizing a name while ignoring a face). Distraction in these tasks is measured as the difference in RT in response to the target when target and distracter afford the same response (congruent) and when they afford opposite responses (incongruent). Mental load is typically induced by requiring participants to hold a string of digits while performing the selection task (e.g., De Fockert et al., 2001). In this paradigm the distractor *must* be processed in order to perform the task (the target must be selected against a competing stimulus). We could refer to this type of distraction as ‘‘selection distraction’’. In the case of the oddball task, the novel stimulus does not have to be processed in order to perform the primary task (e.g., in our task, participants do not need to process the sound in order to respond to the digit) and inevitably hinders performance by virtue of capturing attention away from the primary task. We could refer to this type of distraction as ‘‘orientation distraction’’. Where selection is necessary, and under the reasonable assumption that this selection may require attentional resources, the mobilization of these resources by a secondary task (working memory load maintenance) would necessarily impact performance. Selection would be slower or less efficient. Orientation towards a distractor, on the other hand, is not necessary for participants to judge the subsequent visual target. As a result, orientation distraction occurs when attentional resources are ‘‘available to be captured’’ by a novel sound. A mental load would decrease distraction by mobilizing some of the resources that would otherwise be used to orient attention towards a novel sound, thereby reducing orientation distraction. Future studies will be necessary to test this proposition.

Our task manipulation was designed to increase the difficulty of categorizing the digit and of selecting a response. Relative to the odd/even categorization task, our 4-categories task involved a more demanding rule and doubled the number of stimulus-response mappings, but failed to increase distraction. In fact, in both Experiments 1 and 2, the digit processing manipulations produced robust overall effects but did not increase distraction. The results of these experiments therefore suggest that the locus of distraction in the cross-modal oddball task is neither the early nor the late processing stages of the visual digit. To sum up, the data suggest that distraction is unrelated to the processing of the digit altogether.

If novel sounds slow performance down in the categorization task but none of the processing stages of the visual digit are affected, where does the distraction originate? The logical conclusion is that distraction must *precede* the processing of the visual analysis. Our hypothesis is that, by the time the processing of the visual stimulus starts, distraction has already occurred by delaying the onset of the digit processing. A possible mechanism for this distraction may lie in the shifts of attention between the obligatory processing of the novel sound and the primary task, in line with a bottleneck view of attention (Broadbent, 1958; Pashler et al., 2001; Welford, 1967). Electrophysiological studies have shown that, relative to standards, novels trigger an involuntary orienting of attention embodied by the P3a response (e.g., Escera et al., 1998; Friedman et al., 2001; Näätänen, 1992) and that their content is processed in an obligatory fashion to some extent. There is indeed evidence suggesting that novels not only capture attention but that their features are processed to some extent. For example, Escera et al. (2003) found that familiar novels produce a larger P3a response than unfamiliar novels. Other oddball studies have also shown that even the MMN response is mediated by factors such as the linguistic properties of deviant sounds (Jacobsen et al., 2004), sound meaning (Pulvermüller et al., 2001), or sound familiarity (Jacobsen, Schröger, Winkler, & Horváth, 2005). A recent study by Shtyrov, Hauk, and Pulvermüller (2004) showed that novels made of action words elicit different MMN topographies for a hand-related word ("pick") and a leg-related word ("kick"). Finally, there are indications of a negative wave corresponding to the re-orientation of attention towards the primary task (e.g., Berti & Schröger, 2001; Escera et al., 2001), which was recently suggested to encompass two distinct components: the re-focusing on the relevant task-set in working memory and a general re-orientation in preparation for an upcoming event (Munka & Berti, 2006).

It is therefore possible that the behavioral distraction observed in the digit categorization task following novel irrelevant sounds reflects a delay in attending to the visual stimulus as a result of attention shifts to and back from the auditory novel. Experiment 3 aimed to test this specific hypothesis by examining whether distraction could be reduced or eliminated by forcing attention back towards the primary sensory modality (i.e., visual) prior to the presentation of the target stimulus. This was attempted by presenting an irrelevant visual stimulus between the irrelevant sound and the visual digit to be categorized. The choice of manipulation was based on demonstrations that visual stimuli involuntarily capture attention when such stimuli are characterized by an abrupt visual onset (Remington, Johnston, & Yantis, 1992; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984) and/or motion (either due to motion onset, Abrams & Christ, 2003; or because motion increases the salience of visual objects, Hillstrom & Yantis, 1994). We presented a moving visual stimulus ("X"), displaying both an abrupt onset and motion, between the task-irrelevant sound and the task-relevant visual digit. The prediction was that adding a visual distractor would have the effect of reducing the distraction induced by novel sounds. The visual distractor was hypothesized to re-capture attention away from the novel sound and forcing it back into the visual modality before the presentation of the upcoming digit. If so, this should result in a reduced or abolished distraction caused by the novel sounds.

## 4. Experiment 3

### 4.1. Method

#### 4.1.1. Participants

Twenty (11 females) undergraduates from the University of Plymouth took part in this experiment in exchange for a small honorarium. Participants were aged between 18 and 37 ($M = 22.6$, SD = 6.70). All participants reported correct or corrected-to-normal vision and normal hearing. None of these participants had taken part to either Experiments 1 or 2.

#### 4.1.2. Stimuli, design and procedure

Participants were presented with 4 blocks of 424 trials each. In each trial, participants were required to categorize a digit presented visually as odd or even, as described in the control condition of Experiment 1. Experiment 3 differed in three minor respects: the offset of the sound and the onset of the visual stimulus were separated by 200 ms, the stimuli were presented in white against a black background, and the presentation box was removed.

In addition to the standard and novel conditions as described in our previous experiments, Experiment 3 compared two further conditions. In the *control condition*, the task was as described above. In the *re-capture condition*, a task-irrelevant X was presented 75 ms after the offset of the sound. This X sustained a visual angle of approximately 2.6° at the onset but gradually (linearly) receded to reach a visual angle of approximately 1.6° over 50 ms. A further 75 ms separated the offset of this 'X' and the onset of the target stimulus (see Fig. 4 for an illustration of this condition).

Two blocks of trials were presented in the control and re-capture conditions, presented in alternation (ABAB for half the participants, and BABA for the others). All other aspects of the experiment were as described in Experiment 1.

### 4.2. Results

In this experiment, the visual presentation of an attention-capturing irrelevant stimulus was hypothesized to reduce distraction. In order to carry out a fair test of this hypothesis, we restricted the analysis to those participants who exhibited distraction in the control condition, that is, in the absence of the visual distractor. This was done because a reduction of distraction could only be observed against a baseline distraction effect in the control condition. Fifteen participants were slower in the

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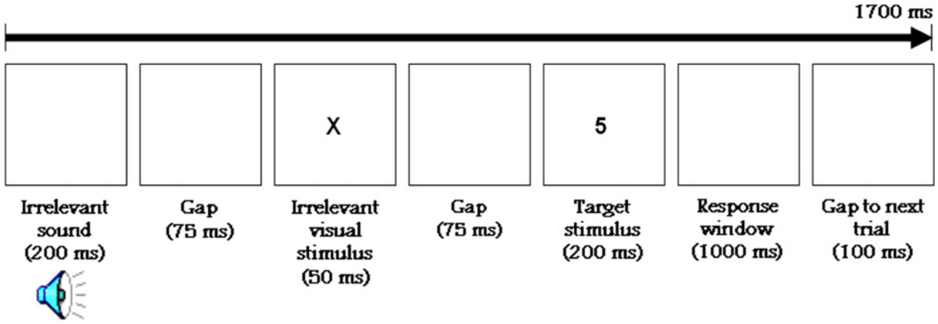


Fig. 4. Schematic representation of a trial in the re-capture condition of Experiment 3. Following the presentation of the irrelevant sound (standard in 90% of trials, novel in the remaining 10%), an irrelevant visual stimulus was presented in the form of an 'X' displaying a receding movement over 50 ms. Participants were instructed to ignore both irrelevant stimuli and to respond to the upcoming visual digit. The control condition of Experiment 3 followed the same trial structure but no visual irrelevant stimulus was presented between the irrelevant sound and the visual digit.

novel condition than in the standard condition in the absence of the re-capture stimulus and were therefore included in the analysis below.[1]

### 4.2.1. Response latencies

Response latencies for correct responses were analyzed in a 2 (control versus re-capture) × 2 (standard versus novel) ANOVA for repeated measures. Participants were significantly faster in the presence of the re-capture stimulus than in its absence, $F(1,14) = 16.321$, $\mathrm{MSE} = 417.499$, $p < .005$, $\eta_p^2 = .538$. A significant effect of distraction was also observed, $F(1,14) = 23.528$, $\mathrm{MSE} = 116.639$, $p < .001$, $\eta_p^2 = .627$. Most importantly, as seen in Fig. 5, distraction diminished in the presence of the re-capture stimulus, $F(1,14) = 12.174$, $\mathrm{MSE} = 64.882$, $p < .005$, $\eta_p^2 = .465$. Planned comparisons confirmed the effect of distraction in the control condition, $F(1,14) = 43.207$, $\mathrm{MSE} = 3238.152$, $p < .001$, $\eta_p^2 = .755$. However, no distraction was observed in the re-capture condition, $F(1,14) = 2.771$, $\mathrm{MSE} = 106.505$, $p = .118$, $\eta_p^2 = .165$.

### 4.2.2. Accuracy

The proportion of correct responses was overall high ($M = .903$, $\mathrm{SD} = .075$). A 2 (control versus re-capture) × 2 (standard versus novel) ANOVA for repeated measures showed that accuracy was not affected by the presence or absence of the re-capture stimulus, $F(1,14) < 1$, $\mathrm{MSE} = .000523$, $p = .691$, $\eta_p^2 = .012$, nor by the type of sound, $F(1,14) < 1$, $\mathrm{MSE} = .001046$, $p = .705$, $\eta_p^2 = .011$. Finally, no interaction

[1] The five participants showing no distraction in the control condition produced, in the re-capture condition, slightly longer RTs ($M = 527.06$, $\mathrm{SD} = 81.79$) and slightly lower accuracy ($M = .84$, $\mathrm{SD} = .17$) in novel condition than in the standard condition ($M = 522.62$, $\mathrm{SD} = 80.55$; and $M = .88$, $\mathrm{SD} = .09$, respectively).

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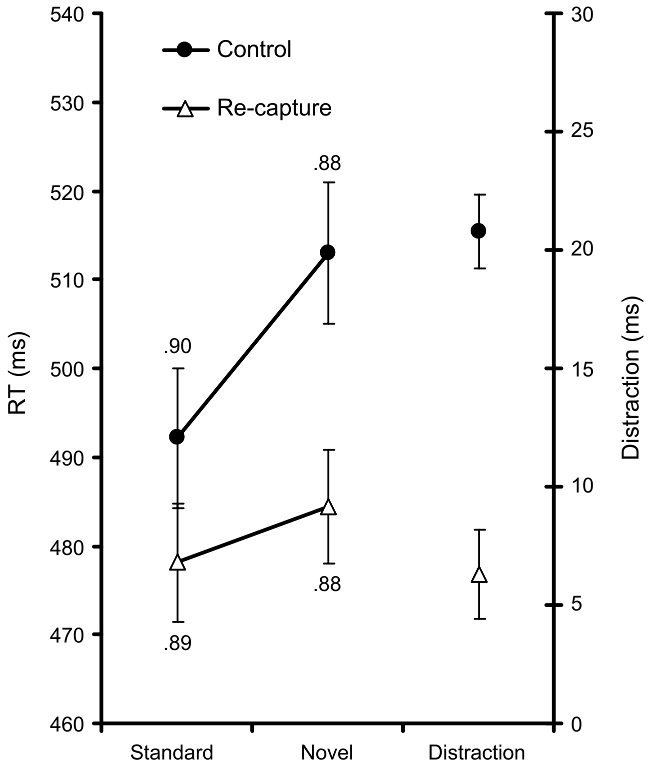


Fig. 5. Performance in Experiment 3. Data points represent the response latencies in the control and re-capture conditions, for the standard and novel sound conditions. The percentage of correct responses for each condition is reported beside each data point. Distraction, defined as $RT_{novel} - RT_{standard}$, is depicted on the right of the figure (secondary *Y*-axis). Error bars represent one standard error of the mean.

was observed between these factors, $F(1,14) < 1$, $MSE = .000555$, $p = .494$, $\eta_p^2 = .034$.

### 4.3. Discussion

Experiment 3 revealed that adding a visual irrelevant stimulus immediately after the irrelevant sound stimulus did not increase distraction but decreased it significantly, in line with the hypothesis that an attention-capturing visual distractor may re-capture attention from the novel and redirect it towards the visual modality. Although this visual distractor was not to be responded to, it reduced response latencies to the target stimulus, suggesting that participants processed it and probably used it as an alert to the upcoming stimulus. The key finding is that the involuntary and obligatory capture of attention by a novel sound can be experimentally neutralized and that our results support the contention that the behavioral distraction effect observed in cross-modal oddball tasks reflects the delayed onset of the target processing due to the shifts of attention, not a reduction of attentional resources available to process the target. The possible nature of the shifts of attention is discussed in the next section.

## 5. General discussion

Participants asked to categorize a digit as odd or even show longer response latencies when this digit is preceded by a novel sound relative to a standard sound (e.g., Escera et al., 2000; Escera & Corral, 2003); an effect we referred to as distraction. While the brain's electrophysiological response to novels has been well described elsewhere, there has been no systematic study of the cognitive locus of distraction with respect to the processing of the digit.

The rationale underpinning Experiments 1 and 2 was that if distraction reflected a reduction on the attention resources available to process the digits, then making the digit processing more demanding should amplify distraction. Experiment 1 showed that varying the demand placed on the visual analysis of the digits did not affect distraction whilst yielding a robust general slowing of responses. Experiment 2 investigated later stages of the digit processing (namely its categorization and the selection of the response). It revealed that distraction was not affected by a nonetheless effective experimental manipulation. *Paribus ceteris*, distraction was unrelated to the target processing demands. Instead, distraction was proposed to reflect the delayed onset of this processing, a delay translating the time penalty resulting from the involuntary shift of attention from the visual task to the novel sound and back to the visual task. This was demonstrated in Experiment 3 by the disappearance of distraction following the re-capture of attention towards the visual modality prior to the presentation of the digit.

With regards to theories of attention, our data favor the bottleneck view (Broadbent, 1958; Pashler et al., 2001; Welford, 1967) of distraction in the cross-modal oddball task over the attentional resource view (Johnston & Heinz, 1978; Kahneman, 1973). Indeed, the latter predicted some interaction between distraction and the attentional demands of the target processing stages. Such interaction was simply not observed in our experiments. Instead, the data are compatible with the idea that the capture of attention by novels had first to be overcome before the processing of the target could start. It is worth noting, however, that the present results do not rule out a role for resource competition in certain circumstances. For example, it is theoretically possible that distraction may stem from a competition between the processing of the novel sound and the processing of the target when the interval between these events is very short (i.e., shorter than in our experiments). There is some evidence compatible with the idea that the content of novel sounds may be analyzed preattentively. Indeed, Escera et al. (2003) found that familiar novel sounds produced more distraction than unfamiliar novel sounds as revealed by electrophysiological measures but not behavioral ones. However, such findings may also reflect differential gating between familiar and unfamiliar novel sounds. Such interpretation would not require the assumption that the content of novel sounds is processed. Further work is necessary to explore this issue. For now, and within the parameters of the experiments we reported, distraction in the cross-modal oddball paradigm is best explained within a bottleneck account.

A practical implication of our findings is that the difficulty of the primary task in the cross-modal oddball may be varied to accommodate the testing of specific populations (e.g., children, clinical populations) while remaining an effective tool to measure behavioral distraction.

## 6. Distraction and target processing

The present study is unique in addressing the processing demands of the target stimulus and measuring their relationship with the distraction entailed by auditory novelty. The use of a cross-modal form of the oddball paradigm allowed us to manipulate the target processing difficulty independently of the discrimination difficulty between targets and distractors. Previous research on distraction and task difficulty focused on the latter. For example, Katayama and Polich (1998), using a one-channel three-tone oddball task, found that when the participants' task was made demanding (difficult discrimination between the standard and the target), the distractive effect of auditory non-target deviants on response latencies and hit rates was enhanced if the perceptual differences between the non-target deviant and the standard were small as opposed to large. Such findings are interesting to understand the perceptual determinants of behavioral and electrophysiological distraction but do not address the issue of the cognitive locus of distraction in the processing of the target independently of its perceptual discrimination from the novels or deviants. One recent study did attempt to address the latter issue (Sabri, Liebenthal, Waldron, Medler, & Binder, 2006). In their study, Sabri et al. (2006) measured the effect of frequency deviants on a duration discrimination task that varied in difficulty (50 ms versus 60 ms in the difficult condition, 50 ms versus 100 ms in the easier condition). Behavioral distraction was observed, as evidenced by a significant delay in response latencies for frequency deviants compared to frequency standards. Response latencies were also overall longer in the difficult discrimination task than in the easier one. Interestingly, however, and in line with our findings, the amount of behavioral distraction was not affected by the difficulty of the discrimination task. The electrophysiology of this distraction did vary as a function of the primary task difficulty, however: the MMN response was larger in the easier task while the N1 and P3a were larger in the harder task. These findings suggest that deviants in the harder task elicited a stronger orienting response. Such findings are interesting in demonstrating that equivalent levels of behavioral distraction can be associated with distinct electrophysiological responses to deviants. With respect to the present study, the results of Sabri et al. suggest that the electrophysiological responses to our novels may potentially differ as a function of the target processing demands. Equally possible, however, is that Sabri et al.'s findings reflect the embedment of deviants and targets within the same auditory objects. It is indeed difficult to argue that the deviant feature (frequency) was unattended when the task requires participants to attend to all sounds and an increase in the target discrimination difficulty arguably increased the participant's focused attention on these sounds. To address this issue, further research should be conducted to examine the role of objecthood (i.e., the binding of features into object percepts) in the interplay between targets and distractors processing, and the effect of this interplay on attention capture. From a cognitive and behavioral perspective, given the immunity of distraction to the target's processing demands in Experiments 1 and 2 and the successful modulation of this distraction by an orienting manipulation in Experiment 3, we provisionally suggest that attention capture is independent of the processing of the target as long as the latter is perceptually distinct from the distractors and unrelated to them in terms of the task set they afford. In the next section, we turn to the discussion of possible accounts of the reduction of distraction in our Experiment 3.

## 7. Mechanisms underpinning cognitive distraction

While our study indicates that distraction is unrelated to the processing of the target but dependent on earlier cognitive operations, there are several potential explanations for the success of the re-capture effect observed in Experiment 3. We evaluate four possible accounts below.

First, according to a spatial attention account, it is possible that our manipulation reduced distraction by cueing attention to the location of the upcoming visual target. The capture of attention by novels may have entailed a shift of spatial attention from the spatial location where the upcoming visual target is expected to the centre of the participant's head (i.e., the perceived location of the binaural novel sounds presented thorough headphones). Our irrelevant visual stimulus may have attracted spatial attention back to the centre of the computer screen, thereby facilitating the prompt processing of the upcoming target. The effectiveness and benefit of a valid spatial cue in directing attention to a specific location is well known even though the exact origin of the effect is still debated (Cheal & Gregory, 1997; Luck, Hillyard, Mouloua, & Hawkins, 1996; Shiu & Pashler, 1994), including across perceptual modalities (e.g., Spence & Driver, 1997, 2004). If so, the corollary assumption would be that novel sounds produce distraction in oddball paradigms through an exogenous shift of spatial attention to an invalid location relative to the upcoming visual target. Such assumption is not warranted, however, for oddball studies in which deviants and targets are both presented from the same spatial auditory location (e.g., Berti & Schröger, 2003) produce electrophysiological responses matching those observed in the cross-modal oddball task (e.g., Escera et al., 2001). Generally, distraction in oddball tasks is thought to operate at an amodal level of attention. Nevertheless, one could not exclude the possibility of a spatial attention factor in our specific cross-modal task.

A second possible mechanism is a shift in perceptual channels, distraction decreasing when a visual distractor redirects attention from the auditory modality to the target's (visual) modality. Under this hypothesis, distraction in the cross-modal oddball task would result from the time penalty incurred when shifting attention from the visual channel to the auditory channel (upon presentation of the novel) and its re-orientation towards the visual channel (upon presentation of the visual target). Presenting an irrelevant visual stimulus prior to the target might disrupt the orientation of attention towards the novel or redirect attention towards the visual channel. This hypothesis would fit with the finding of longer response latencies when participants attend to sequential stimuli presented in different modalities relative to ipsimodal stimuli (Boulter, 1977; Harvey, 1980). Interestingly, Turatto, Benso, Galfano, and Umiltà (2002) reported that participants responding to a stimulus S2 following a task-irrelevant stimulus S1 exhibited longer response latencies for auditory S1 and visually S2 compared to visual S1 and S2, even though both stimuli shared the same spatial location (ruling out the spatial shift account) and the modality of presentation of S2 was fixed and known to participants. Our results fit these authors' conclusion that "once S1 is presented, regardless of whether it has to be actively processed or ignored, central mechanisms are briefly automatically set to the corresponding modality, facilitating the processing of an ipsimodal S2 (...) but delaying attentional resources for central processing of a cross-modal S2" (p. 638).

A third possible mechanism through which our re-capture manipulation may have reduced distraction is by triggering the early re-activation of the digit categorization task set. A recent study suggests that the P3a response observed in oddball tasks in response to auditory novels or deviants shares the topographical characteristics of the electrophysiological activity observed in task switching (Barceló, Escera, Corral, & Periañez, 2006). Using a modified version of the Madrid Card Sorting Task, these authors showed a P3 response of equivalent scalp distribution in response to infrequent task-irrelevant novel sounds and cues signaling a change of sorting criterion. Further, they demonstrated that a common neural network processing contextual novelty (Barceló, Periañez, & Knight, 2002). Based on the idea of a functional equivalence between novelty detection and task switching, one may propose that the behavioral distraction in the cross-modal oddball task reflects the de-activation of the task-relevant for the upcoming target by novels (the latter introducing a change in the task context, or some uncertainty) in favor of a different task set. Of course, because participants in the cross-modal oddball task are instructed to ignore the sounds, one may question whether there can be a novel-related task. However, the fact that some aspects of novels or deviants are analyzed in oddball tasks (Escera et al., 2003; Jacobsen et al., 2004; Jacobsen et al., 2005; Pulvermüller et al., 2001; Shtyrov et al., 2004) may allow one to consider that the processing of the novel as a task executed by the brain, even if not voluntarily by the participant.

If we assume that novels and targets elicit distinct task sets and that distraction reflects the cost of switching between these, how would our visual distractor help overcome the switch cost? While our visual distractor did not afford the response categories odd or even, its visual nature (shared by the target) may have sufficed to act as a task cue. The literature on task switching shows that the reconfiguration of one's mental set is not complete until the presentation of the post-switch stimulus (e.g., Rogers & Monsell, 1995). However, task cues allowing the early activation of the relevant task-set have been shown to reduce significantly the switch cost (Dreisbach, Haider, & Kluwe, 2002; Rubinstein, Meyer, & Evans, 2001; Spector & Biederman, 1976). In summary, according to the task switch account of our re-capture effect, the visual distractor acted as a task cue ahead of the target, thereby reducing the cost of switching from the analysis of the novel to the processing of the target. A task switch account of our re-capture effect may not be entirely satisfactory, however, because the results of Experiment 2 challenge its corollary assumption, namely that distraction in oddball tasks translates the time required to re-activate the task-set relevant to the upcoming stimulus. Indeed, re-activating the 4-categories task-set and response mappings should be more demanding than re-activating the over learnt odd/even task set. In turn, a larger effect of distraction should have been observed in the 4- than the 2-categories condition.

Fourth, the reduction of distraction in Experiment 3 may be explained by a contextual account according to which rare contextual changes may impair the selection of a response. Barceló et al. (2006) proposed that the novelty P3 reflects the entropy conveyed by a stimulus with respect to stimulus-response mappings. If a response R1 is associated with a response S1 with a high occurrence rate, then S1 becomes a good predictor of R1. In turn, the quantity of information or entropy it conveys about the response would be small. In this conceptual framework, every stimulus is mapped to a response. In the case of task-irrelevant standards or novels, their associate response is to produce no response. Novels are particular, however, because they are rare. As such, the selection of a response cannot rely on well established stimulus-response mappings. The novelty P3, according to Barceló et al. (2006) may therefore mark the amount of stimulus-response entropy associated with rare events. If we borrow from their study the idea that infrequent changes in task context are responsible for distraction, an account of the results of our Experiment 3 can be suggested. Indeed, if one considers both our auditory (A) and visual (V) distractors as the context in which the target is presented, then a novel may bring less contextual change in the presence of the visual distractor than in its absence, because the latter was held constant within a block of trials. In other words, because contexts $A_{novel}V$ and $A_{standard}V$ share the V element, their overall similarity would be superior to that between $A_{novel}$ and $A_{standard}$. The $A_{novel}V$ and $A_{standard}V$ may introduced less stimulus-response entropy because they share an element (V) strongly associated with a no-response.

In conclusion, distraction in the cross-modal oddball task can be reduced or eliminated experimentally simply by presenting a task-irrelevant visual stimulus between the task-irrelevant sound and the visual target stimulus. Our results highlight the importance of understanding the exact nature of the processes at play before the onset of the target in order to develop a mechanistic model of distraction. Four accounts were proposed, all involving the notion of a shift (be it of spatial attention, of sensory modality, or of task set or of stimulus-response mapping). Further research is required to disentangle these further.

Finally, it is worth pointing out that while our data suggest that distraction is not related to the processing of the target, the experimental manipulations that successfully reduced distraction (complex categorization task in Experiment 2 and presentation of an attention-grabbing distractor between the novel sound and the visual target) most probably affected the pre-attentive processing of the novel sound. For recall, Berti and Schröger (2003) found that a working memory load reduced the P3a and RON responses to a novel sound, suggesting that the orientation of attention to and from a novel sound is reduced when attentional resources are engaged in the concurrent maintenance of information in working memory. It is reasonable to assume that the reduction of distraction in Experiment 2 reflected a similar effect, especially since the increase in task difficulty we used did not require the enhanced processing of task-irrelevant sound. When task difficulty is manipulated in a way that increases the processing of task-irrelevant features, however, a working memory load can augment, instead of diminish, the impact of irrelevant novel stimuli (Muller-Gass & Schröger, 2007). Finally, in our Experiment 3, the automatic return of attention towards the visual modality would most certainly have consequences for the pre-attentive processing of the novel sound. While this is a matter for future electrophysiological work, one may hypothesize that the re-capture of attention into the visual modality in Experiment 3 may have decreased distraction because the orientation of attention towards the novel sound was interrupted or prevented by the presentation of an attention-grabbing visual distractor.

## 8. Summary

Across three experiments, we reported that distraction in the cross-modal oddball task does not relate to the processing of the target stimulus but to the cognitive operations executed ahead of it. We tested the hypothesis that distraction resulted from the diversion of attention away from the visual target by demonstrating that a task-irrelevant visual stimulus is able to re-orient attention towards the primary task. From a theoretical perspective, our results call for further investigation of the possible mechanisms underpinning this re-capture effect. A practical implication of the present study is that the demands of the primary task in the cross-modal oddball task may safely be adapted to the testing of specific age or clinical populations without jeopardizing the measurement of attention capture by novel events.

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## References

Abrams, R. A., & Christ, S. E. (2003). Motion onset captures attention. *Psychological Science, 14*, 427–432.

Alho, K., Escera, C., Díaz, R., Yago, E., & Serra, J. M. (1997). Effects of involuntary auditory attention on visual task performance and brain activity. *NeuroReport, 8*, 3233–3237.

Alho, K., Winkler, I., Escera, C., Huotilainen, M., Virtanen, J., Jääskeläinen, I., et al. (1998). Processing of novel sounds and frequency changes in the human auditory cortex: Magnetoencephalographic recordings. *Psychophysiology, 35*, 211–224.

Andrés, P., Parmentier, F. B. R., & Escera, C. (2006). The effect of age on involuntary capture of attention by irrelevant sounds: A test of the frontal hypothesis of aging. *Neuropsychologia, 44*, 2564–2568.

Banbury, S., & Berry, D. C. (1997). Habituation and dishabituation to speech and office noise. *Journal of Experimental Psychology: Applied, 3*, 1–16.

Banbury, S., & Berry, D. C. (1998). The disruption of office-related tasks by speech and office noise. *British Journal of Psychology, 89*, 285–295.

Barceló, F., Escera, C., Corral, M.-J. & Periañez, J.A. (2006). Task switching and novelty processing activate a common neural network for cognitive control. *Journal of Cognitive Neuroscience, 18*, 1734–1748.

Barceló, F., Periañez, J. A., & Knight, R. T. (2002). Think differently: A brain orienting response to task novelty. *NeuroReport, 13*, 1887–1892.

Berti, S., Roeber, U., & Schröger, E. (2004). Bottom-up influences on working memory: Behavioral and electrophysiological distraction varies with distractor strength. *Experimental Psychology, 51*, 249–257.

Berti, S., & Schröger, E. (2001). A comparison of auditory and visual distraction: Behavioral and event-related indices. *Cognitive Brain Research, 10*, 265–273.

Berti, S., & Schröger, E. (2003). Working memory controls involuntary attention switching: Evidence from an auditory distraction paradigm. *European Journal of Neuroscience, 17*, 1119–1122.

Boulter, L. R. (1977). Attention and reaction times to signals of uncertain modality. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 379–388.

Broadbent, D. E. (1958). *Perception and communication*. New York: Pergamon.

Cheal, M., & Gregory, M. (1997). Evidence of limited capacity and noise reduction with single-element displays in the location-cuing paradigm. *Journal of Experimental Psychology: Human Perception & Performance, 23*, 51–71.

De Fockert, J. W., & Lavie, N. (2001). The role of working memory in attentional capture. *Psychonomic Bulletin & Review, 12*, 669–674.

De Fockert, J. W., Rees, G., Frith, C., & Lavie, N. (2001). The role of working memory load in selective attention. *Science, 291*, 1803–1806.

Dornheim, M. A. (2000). Crew distractions emerge as a new safety focus. *Aviation Week & Space Technology, 17*, 58–60.

Dreisbach, G., Haider, H., & Kluwe, R. H. (2002). Preparatory processes in the task-switching paradigm: Evidence for the use of probability cues. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 28*, 468–483.

Escera, C., Alho, K., Schröger, E., & Winkler, I. (2000). Involuntary attention and distractibility as evaluated with event-related brain potentials. *Audiology & Neuro-Otology, 5*, 151–166.

Escera, C., Alho, K., Winkler, I., & Näätänen, R. (1998). Neural mechanisms of involuntary attention to acoustic novelty and change. *Journal of Cognitive Neuroscience, 10*, 590–604.

Escera, C., & Corral, M.-J. (2003). The distraction potential (DP), an electrophysiological tracer of involuntary attention control and its dysfunction. In I. Reinvang, M. W. Greenlee, & M. Hermann (Eds.), *The cognitive neuroscience of individual differences* (pp. 63–76). Oldenburg: Bibliotheks-und Informationsystem des Universität Oldenburg.

Escera, C., Corral, M. J., & Yago, E. (2002). An electrophysiological and behavioral investigation of involuntary attention towards auditory frequency, duration and intensity changes. *Cognitive Brain Research, 14*, 325–332.

Escera, C., Yago, E., & Alho, K. (2001). Electrical responses reveal the temporal dynamics of brain events during involuntary attention switching. *European Journal of Neuroscience, 14*, 877–883.

Escera, C., Yago, E., Corral, M.-J., Corbera, S., & Nuñez, M. I. (2003). Attention capture by auditory significant stimuli: Semantic analysis follows attention switching. *European Journal of Neuroscience, 18*, 2408–2412.

Friedman, D., Cycowicz, Y. M., & Gaeta, H. (2001). The novelty P3: An event-related brain potential (ERP) sign of the brain's evaluation of novelty. *Neuroscience & Biobehavioral Reviews, 25*, 355–373.

Grillon, C., Courchesne, E., Ameli, R., Geyer, M., & Braff, D. L. (1990). Increased distractibility in schizophrenic patients. *Archives of General Psychiatry, 47*, 171–179.

Harvey, N. (1980). Non-informative effects of stimuli functioning as cues. *Quarterly Journal of Experimental Psychology, 32*(A), 413–425.

Hillstrom, A. P., & Yantis, S. (1994). Visual-motion and attentional capture. *Perception and Psychophysics, 55*, 399–411.

Hughes, R. W., Vachon, F., & Jones, D. M. (2005). Auditory attentional capture during serial recall: Violation at encoding of an algorithm-based neural model? *Journal of Experimental Psychology: Learning Memory, and Cognition, 31*, 736–749.

Jacobsen, T., Horváth, J., Schröger, E., Lattner, S., Widmann, A., & Winkler, I. (2004). Pre-attentive auditory processing of lexicality. *Brain and Language, 88*, 54–67.

Jacobsen, T., Schröger, E., Winkler, I., & Horváth, J. (2005). Familiarity affects the processing of task-irrelevant auditory deviance. *Journal of Cognitive Neuroscience, 17*, 1704–1713.

Johnston, W. A., & Heinz, S. P. (1978). Flexibility and capacity demands of attention. *Journal of Experimental Psychology: General, 107*, 420–435.

Jones, D. M., Alford, D., Bridges, A., Tremblay, S., & Macken, W. J. (1999). Organizational factors in selective attention: The interplay of acoustic distinctiveness and auditory streaming in the irrelevant sound effect. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 25*, 464–473.

Jones, D. M., & Broadbent, D. E. (1991). Human performance and noise. In C. M. Harris (Ed.), *Handbook of acoustical measurements and noise control* (pp. 241–2424). New York: Mc Graw-Hill.

Jones, D. M., Farrand, P., Stuart, G., & Morris, N. (1995). Functional equivalence of verbal and spatial information in serial short-term memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 21*, 1008–1018.

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 19*, 369–381.

Jones, D. M., Madden, C., & Miles, C. (1992). Privileged access by irrelevant speech to short-term memory: The role of changing state. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 44 A*, 645–669.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.

Katayama, J., & Polich, J. (1998). Stimulus context determines P3a and P3b. *Psychophysiology, 35*, 23–33.

Lange, E. B. (2005). Disruption of attention by irrelevant stimuli in serial recall. *Journal of Memory & Language, 53*, 513–531.

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9*, 75–82.

Luck, S. J., Hillyard, S. A., Mouloua, M., & Hawkins, H. L. (1996). Mechanisms of visual-spatial attention: Resource allocation or uncertainty reduction?. *Journal of Experimental Psychology: Human Perception and Performance 22*, 725–737.

May, D. N., & Rice, C. G. (1971). Effects of startle due to pistol shots on control precision performance. *Journal of Sound and Vibration, 15*, 197–202.

Muller-Gass, A., & Schröger, E. (2007). Perceptual and cognitive task difficulty has differential effects on auditory distraction. *Brain Research, 1136*, 169–177.

Munka, L., & Berti, S. (2006). Examining task-dependencies of different attentional processes as reflected in the P3a and reorienting negativity components of the human event-related brain potential. *Neuroscience Letters, 396*, 177–181.

Näätänen, R. (1992). *Attention and brain function*. Hillsdale, NJ: Erlbaum.

Näätänen, R., & Winkler, I. (1999). The concept of auditory stimulus representation in cognitive neuroscience. *Psychological Bulletin, 6*, 826–859.

Opitz, B., Rinne, T., Mecklinger, A., von Cramon, D. Y., & Schröger, E. (2002). Differential contribution of frontal and temporal cortices to auditory change detection: fMRI and ERP results. *NeuroImage, 15*, 165–174.

Pashler, H., Johnston, J. C., & Ruthruff, E. (2001). Attention and performance. *Annual Review of Psychology, 52*, 629–651.

Picton, T. W., Alain, C., Otten, L., Ritter, W., & Achim, A. (2000). Mismatch negativity: Different water in the same river. *Audiology & Neuro-Otology, 5*, 111–139.

Pulvermüller, F., Kujala, T., Shtyrov, Y., Simola, J., Tiitinen, H., Alku, P., et al. (2001). Memory traces for words as revealed by the mismatch negativity. *Neuroimage, 14*, 607–616.

Remington, R. W., Johnston, J. C., & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. *Perception & Psychophysics, 51*, 279–290.

Roeber, U., Berti, S., & Schröger, E. (2003). Auditory distraction with different presentation rates: An even-related potential and behavioral study. *Clinical Neurophysiology, 114*, 341–349.

Rogers, R. D., & Monsell, S. (1995). The cost of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231.

Rubinstein, J., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 763–797.

Sabri, M., Liebenthal, E., Waldron, E. J., Medler, D. A., & Binder, J. R. (2006). Attentional modulation in the detection of irrelevant deviance: A simultaneous ERP/fMRI study. *Journal of Cognitive Neuroscience, 18*, 689–700.

Schröger, E. (1996). A neural mechanism for involuntary attention shifts to changes in auditory stimulation. *Journal of Cognitive Neuroscience, 8*, 527–539.

Schröger, E., & Wolff, C. (1998a). Attentional orienting and reorienting is indicated by human event-related brain potentials. *NeuroReport, 9*, 3355–3358.

Schröger, E., & Wolff, C. (1998b). Behavioral and electrophysiological effects of task-irrelevant sound change: A new distraction paradigm. *Brain Research. Cognitive Brain Research, 7*, 71–87.

Shimamura, A. P. (1994). Neuropsychological perspectives on memory and cognitive decline in normal human aging. *Seminars in the Neurosciences, 6*, 387–394.

Shiu, L., & Pashler, H. (1994). Negligible effect of spatial precuing on identification of single digits. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1037–1054.

Shtyrov, Y., Hauk, O., & Pulvermüller, F. (2004). Distributed neuronal networks for encoding category-specific semantic information: The mismatch negativity to action words. *European Journal of Neuroscience, 19*, 1083–1092.

Spector, A., & Biederman, I. (1976). Mental set and switch revisited. *American Journal of Psychology, 89*, 669–679.

Spence, C., & Driver, J. (1997). Audiovisual links in exogenous covert spatial orienting. *Perception & Psychophysics, 59*, 1–22.

Spence, C., & Driver, J. (2004). *Crossmodal space and crossmodal attention*. Oxford, UK: Oxford University Press.

Stekelenburg, J. J., Vroomen, J., & deGelder, B. (2004). Illusory sound shifts induced by the ventriloquist illusion evoke the mismatch negativity. *Neuroscience Letters, 357*, 163–166.

Tremblay, S., Macken, W. J., & Jones, D. M. (2001). The impact of broadband noise on serial memory: Changes in band-pass frequency increase disruption. *Memory, 9*, 323–331.

Turatto, M., Benso, F., Galfano, G., & Umiltà, C. (2002). Nonspatial attentional shifts between audition and vision. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 628–639.

Welford, A. T. (1967). Single-channel operation in the brain. *Acta Psychologica, 27*, 5–22.

Woodhead, M. M. (1959). Effect of brief loud noise on decision making. *The Journal of the Acoustical Society of America, 31*, 1329–1331.

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Woodhead, M. M. (1964). The effect of bursts of noise on an arithmetic task. *The American Journal of Psychology, 77*, 627–633.

Woods, D. L. (1992). Auditory selective attention in middleaged and elderly subjects: An event-related brain potential study. *Electroencephalography and Clinical Neurophysiology, 84*, 456–468.

Yantis, S., & Hillstrom, A. P. (1994). Stimulus-driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 95–107.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception & Performance, 10*, 601–621.