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REVIEW

The cognitive determinants of behavioral distraction by deviant auditory stimuli: a review

Fabrice B. R. Parmentier

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Abstract Numerous studies have demonstrated that rare and unexpected changes in an otherwise repetitive or structured sound sequence ineluctably break through selective attention and impact negatively on performance in an unrelated task. While the electrophysiological responses to unexpected sounds have been extensively studied, behavioral distraction has received relatively less attention until recently. In this paper, I review work examining the cognitive underpinnings of behavioral distraction by deviant sounds and highlight some of its key determinants. Evidence indicates that deviance distraction (1) derives from the time penalty associated with the involuntary orientation of attention to and away from the deviant sound and from resulting effects such as the reactivation of the relevant task set upon the presentation of the target stimulus; and (2) is mediated by a number of factors (some increasing distraction, such as aging or induced emotions; some decreasing it, such as a memory load or cognitive control). Contrary to the received view that deviants ineluctably elicit distraction, recent work demonstrates that it is contingent upon auditory distractors acting as unspecific warning signals in the service of goal-oriented behavior, and that deviants do not elicit distraction because they are rare but because they violate the cognitive system's predictions (which can be manipulated through implicit rule learning or explicit cueing). Evidence is also presented indicating that the capture of attention by spoken deviant sounds is followed by an involuntary evaluation of their semantic properties, the outcome of which can be robust enough to linger in working memory and interfere with subsequent behavior. Finally, I review studies suggesting that behavioral deviance distraction is not the mere byproduct of the mismatch negativity, P3a and re-orientation negativity electrophysiological responses and highlight a number of outstanding questions for future research.

F. B. R. Parmentier (✉)
Department of Psychology and Research Institute of Health Sciences, Neuropsychology and Cognition Group, University of the Balearic Islands, Ctra. De Valldemossa, Km 7.5, Palma de Mallorca, Balearic Islands, Spain
e-mail: fabrice.parmentier@uib.es

F. B. R. Parmentier
Department of Psychology, University of Western Australia, Crawley, Australia

Introduction

Efficient cognitive functioning often requires the ability to filter out task-irrelevant stimuli in order to concentrate on a task at hand. At the same time, it is also adaptive and important for an organism to detect sudden changes in its immediate environment by letting certain stimuli break through attention filters. A trade-off between selective attention and change detection is advantageous and may arguably have played an important role in the evolution of our cognitive system. This trade-off, while possibly providing an optimal solution to these divergent necessities, may come at a cost: distraction. To illustrate the point, imagine reading this article while seated at the terrace of a café on a busy city street. Filtering out street noises and conversations between nearby individuals definitely helps focusing on the article's content but it is not bulletproofed, for on occasions your attention will involuntarily switch to task-irrelevant stimuli. These may be of potential importance and require further processing or some action (e.g., the nearby sound of screeching tires), but may also capture attention despite being inconsequential (e.g., someone nearby speaking in an unusual voice). One class of stimuli particularly prone to yield distraction, and which can be reliably studied in the laboratory, is unexpected changes in our auditory surroundings (deviant stimuli). Deviant stimuli are defined as stimuli that violate predictions by deviating from an otherwise repetitive or structured sequence and can do so based on the relatively low-level characteristics (such as sensory features) or more abstract ones (such as a rule). The distraction yielded by deviant stimuli (referred to as deviance distraction hereafter) is characterized by specific electrophysiological markers (briefly described below) and a behavioral effect. In a task where participants attend and respond to a target stimulus or stimulus feature, behavioral deviance distraction is defined as the lengthening of response times and, sometimes, the reduction in response accuracy, following the presentation of a deviant sound. Recent experimental work has begun to unpick the cognitive mechanisms underpinning this behavioral effect (compared to that of a standard or predictable sound). Such enterprise is especially warranted given the increasing evidence that behavioral deviance distraction is not merely a byproduct of the responses measured by electrophysiological indexes of attention capture and the orienting response. In this article I will present a brief summary of some key findings in the field and outline some outstanding questions and avenues for future research.[1]

Electrophysiological and behavioral distraction by unexpected sounds

Over 30 years ago, Näätänen, Gaillard, and Mäntysalo (1978) coined the term "mismatch negativity" (or MMN) to describe a negative deflection observed in response to rare and unexpected loudness or pitch changes in an otherwise repeated tone sequence that participants did not voluntarily attend. This response, typically emerging some 100–150 ms following the onset of a deviant sound, was to be the subject of intense empirical research (e.g., Näätänen, 1992) and to pioneer the idea that the auditory system is equipped with a fast and efficient mechanism to detect events that do not match its memory for past or predicted events (for reviews, see Czigler & Winkler, 2012; Kujala, Tervaniemi, & Schröger, 2007; Schröger, 2005, 2007; Winkler, 2007).

One important offshoot of this line of research has been the finding by Schröger (1996) of a later electrophysiological response to auditory deviance (namely the P3a response typically regarded as marking the involuntary orientation of attention toward the deviant stimulus; Friedman, Cycowicz, & Gaeta, 2001; Grillon, Courchesne, Ameli, Geyer, & Braff, 1990; Woods, 1992) and the behavioral impact of deviance on performance in an unrelated task. Numerous electrophysiological studies have since investigated the electrophysiological and behavioral impact of unattended auditory oddball stimuli (referred to as novel or deviant sounds depending on whether they are unique in the task's context or are presented on several occasions across it) in a train of otherwise repeated, structured or predictable sounds (referred to as standard sounds). Oddball sounds are known to yield a triumvirate of responses (e.g., Schröger, 1997; Schröger, Giard, & Wolff, 2000; Schröger, & Wolff, 1998a, b): MMN, P3a (sometimes referred to as novelty P3; see Friedman et al., 2001, for a review) and re-orientation negativity (RON; e.g., Schröger, & Wolff, 1998b). The P3a response marks the involuntary orientation of attention towards a deviant or novel sound (Friedman et al., 2001; Grillon et al., 1990; Woods, 1992) and is thought to result from an attentional interruption involving frontal areas (Opitz, Rinne, Mecklinger, von Cramon, & Schröger, 2002). A later re-orientation negativity is observed when participants are performing a primary task and must redirect their attention towards that task (Berti, 2008a; Berti, Roeber, & Schröger, 2004; Berti, & Schröger, 2001; Escera, Yago, & Alho, 2001), which is thought to involve both the "refocusing on task-relevant information on the working memory level, and general reorientation of attention after distraction in the sense of preparation for the task at hand" (Munka & Berti, 2006, p. 181).

Of key interest in the context of this article is the finding that novel and deviant sounds yield *behavioral* distraction (e.g., Schröger, 1996), typically by delaying responses to a target stimulus (and sometimes also by reducing response accuracy), such as when participants must judge the duration of tones in the face of rare and irrelevant changes in pitch (e.g., Berti, & Schröger, 2003, 2004, see also Horváth, & Burgyán, 2011, for an extension of this phenomenon to the attentional blink effect; and Horváth & Winkler, 2010, for evidence of distraction in a continuous stimulation task). The generality of this distraction effect is emblematized by the finding that it is not limited to auditory oddball tasks (e.g., Berti, 2008a; Berti, & Schröger, 2003; Grimm, Schröger, Bendixen, Bäβ, Roye, & Deouell, 2008; Horváth, & Winkler; 2010; Reiche, Hartwigsen, Widmann, Saur, Schröger, & Bendixen, 2013, Roeber, Widmann, & Schröger, 2003; Schröger, 1996) but also applies to visual (Berti, & Schröger, 2004; Boll, & Berti, 2009; Grimm, Bendixen, Deouell, & Schröger, 2009), auditory–visual (Andrés, Parmentier, & Escera; 2006; Ljungberg, & Parmentier, 2012a; Parmentier, & Andrés, 2010; Parmentier, Elsley, & Maybery, 2010; Munka & Berti, 2006; SanMiguel, Linden, & Escera, 2010) and

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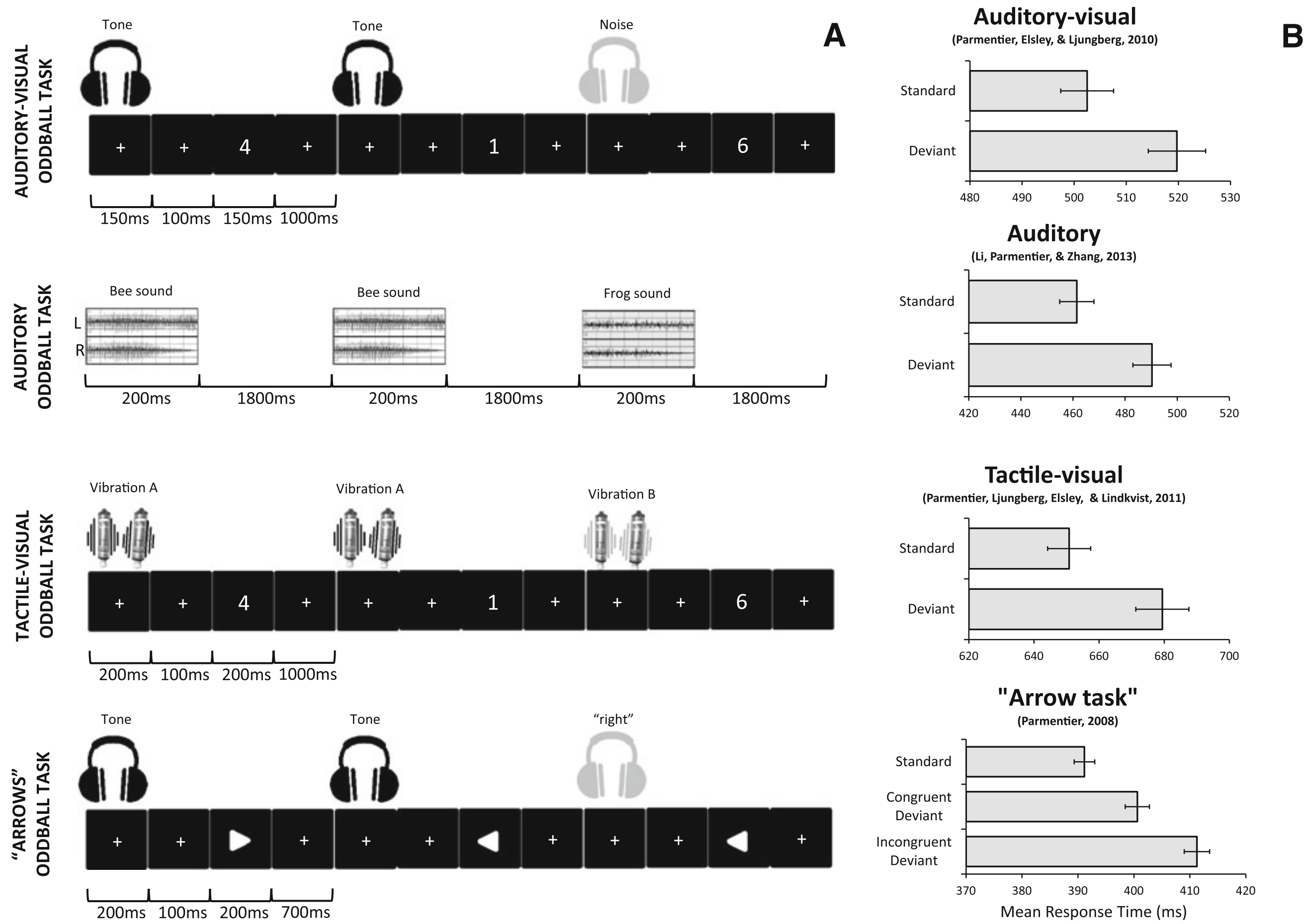

Fig. 1 Schematic illustration of the method and empirical findings from four variations of the oddball task. **a** Trials from the auditory–visual (Parmentier et al., 2010, $n = 32$), auditory (Li et al., 2013, data taken from the informative condition, $n = 20$), and tactile–visual (Parmentier, et al., 2011, $n = 36$), and "arrow" (Parmentier, 2008, data compiled from Experiments 1–4, $n = 120$) oddball tasks. In each task participants responded to a target stimulus or stimulus feature (parity of digit in the auditory–visual and tactile–visual tasks, direction of movement of a sound in the auditory task, and direction pointed by an *arrow* in the *arrow* task) while instructed to ignore a task-irrelevant stimulus or stimulus feature that changed one rare and unpredictable trials (change from a tone to white noise in the auditory–visual task, change of sound identity in the auditory task, change in speed and amplitude of a task-irrelevant vibration—delivered through bespoke hand-held vibrating devices—in the tactile–visual task, and change from a tone to the word "left" or "right" in the *arrow* task). **b** The deviance distraction in all tasks (significantly longer response times in the deviant condition relative to the standard condition). In addition, a semantic effect was observed in the *arrow* task whereby deviant words incongruent with the upcoming arrow (e.g., "right" followed by a *left arrow*) yielded longer response times than congruent deviant words (note that the example depicted in the *left panel* here only illustrates the standard and incongruent conditions). *Error bars* represent one standard error of the mean

tactile–visual (Ljungberg, & Parmentier, 2012b; Parmentier, Ljungberg, Elsley, & Lindkvist, 2011) tasks. The first two typically involve the presentation of target and task-irrelevant features as part of the same perceptual object. In contrast, cross-modal tasks use perceptually and temporally decoupled stimuli to convey target and task-irrelevant information separately. For example, in the auditory–visual oddball task (e.g., Escera et al., 1998; Jääskeläinen, Alho, Escera, Winkler, Sillanaukee, & Näätänen, 1996; Parmentier, 2008; van Mourik, Oosterlaan, Heslenfeld, Konig, & Sergeant, 2007), participants are typically asked to categorize visual stimuli (e.g., categorizing digits based on their parity) and ignore auditory stimuli presented immediately before each target. Participants typically respond slower (and occasionally less accurately) to visual stimuli following novel or deviant sounds compared to the standard sound (e.g., Andrés et al., 2006; Bendixen, Grimm, Deouell, Wetzel, Mädebach, & Schröger, 2010; Boll, & Berti, 2009; Ljungberg, & Parmentier, 2012a, b; Parmentier, & Andrés, 2010; Parmentier et al., 2010). Figure 1 (Panel A) illustrates the main methodological characteristics of four tasks (auditory–visual, tactile–visual, auditory oddball tasks, as well as the arrow task described later in this article) and (Panel B) evidence of the presence of deviance distraction in each case.

My initial interest in novelty distraction stemmed from a simple question: why should we be slower to judge the parity of a visual digit if it is preceded by a novel sound? Past work using the cross-modal oddball task focused on the electrophysiological responses to auditory novelty rather than the behavioral aspects of distraction per se, the latter being typically regarded as an end-product correlate of the cognitive mechanisms highlighted by the electrophysiological responses. Yet the question deserves some attention, for ignoring a stream or task-irrelevant sounds and categorizing visual target digits do not appear to share much in the way of cognitive processing. My curiosity probably owed much to the notion, widespread in memory research, that a slower response to a stimulus reflects the slowing of some or several part(s) of its processing and the intuitive hypothesis that distraction must result from divided attention (deviant sounds capturing attention and thereby depleting the resources available for the processing of the target). As it turned out, evidence showed that the slowing of responses in the visual task appears not to reflect the slower processing of the visual targets per se but, instead, time penalties due to shifts of attention to and from the novel sounds (Parmentier, Elford, Escera, Andrés, & SanMiguel, 2008). This conclusion was based on the finding that increasing the visual task's cognitive demands on early visual processing or categorization and response selection did not increase distraction. Inserting an abrupt visual distractor between the task-irrelevant auditory stimulus and the visual target eliminated novelty distraction, however. That is, distraction was eliminated when the participant's attention was exogenously forced away from the novel sound before the target stimulus' presentation. The findings from Parmentier et al. (2008) are in line with Schröger's (1996) conclusion that "the behavioral effects may be regarded as a result of an involuntary attention switch triggered by a task-irrelevant deviant event" (p. 533). Such definition of behavioral deviance distraction accounts not only for the effect of deviant sounds on response time but also for the occasional finding of a diminution in response accuracy through variations in a speed-accuracy trade-off: on occasions responses are fired up before sufficient evidence is accumulated from the stimulus, which results in an increase of selecting the incorrect response (e.g., Luce, 1986).

The exact nature of the shift of attention elicited by deviant sounds remains to be established, though Parmentier et al. (2008) highlighted three possible, not mutually exclusive, candidates. First, in the case of the cross-modal oddball task, where task-irrelevant auditory stimuli and visual targets are presented in distinct spatial locations (center of the head through binaural presentation, and on the computer screen, respectively), novel sounds may elicit a shift of spatial attention from the spatial location where the upcoming visual target is expected to the novel sound's location (standard sounds, due to habituation, do not enter the focus of attention and therefore do not elicit such shift) and then back to the target's location upon its presentation. Assuming that such spatial shifts require time to complete (Cheal & Gregory, 1997; Luck, Hillyard, Mouloua, & Hawkins, 1996; Shiu, & Pashler, 1994), it might contribute to novelty distraction. Such cost could not, however, account for distraction in purely auditory oddball tasks where task-irrelevant and target information share the same location.

A second possible type of attentional shift at play in cross-modal oddball tasks may be between sensory modalities. Under this hypothesis, distraction would result from the time penalty incurred when shifting attention from the visual to the auditory channel (upon presentation of the novel sound) and its re-orientation towards the visual channel (upon presentation of the visual target). This contention is certainly in line with the response time (RT) cost observed in tasks where participants attend to sequential stimuli presented across different modalities relative to ipsimodal stimuli (Boulter, 1977; Harvey, 1980) and Turatto, Beson, Galfano, and Umiltà's (2002) 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 type of shift, this time applying to cross-modal and ipsimodal oddball tasks alike, relates to the notion of task set shifting. According to this hypothesis, distraction occurs because upon the novel sound's involuntarily intrusion in the focus of attention, the cognitive system attempts to determine the appropriate response to this stimulus. This may especially be the case in the context of a sustained attention task in which participants' overarching goal is to produce fast actions in response to rapidly presented stimuli. If we assume that not producing a response is the appropriate response to a novel sound, then this stimulus–response mapping can be distinguished from those belonging to the primary task and novel sounds can be construed as forcing a switch of task sets. The notion that not responding may constitute a response in itself is not a farfetched one. For example, recent work on response suppression increasingly suggests that withholding a response can be viewed as the result of associative learning (e.g., Chiu, Aron, & Verbruggen, 2012; Verbruggen, & Logan, 2008). Interestingly, Hölig, and Berti (2010) provided evidence of a direct link between distraction and task switching using an auditory location discrimination task in which a rare pitch deviance was either irrelevant or signaled to participants to switch to a pitch categorization task. Both conditions elicited MMN, P3a and RON responses, prompting the authors to argue that "similar attentional control mechanisms underlie distraction and task switching" (p. 171). Additional evidence is also found in a visual memory updating task where a switch between memory representations elicits a P3a response, thereby questioning the notion that this response is limited to an involuntary orientation of attention (Berti, 2008b).

Evidence demonstrates that the time penalty element described above is one of the contributors to behavioral distraction but that more complex factors are at play too. For example, Roeber, Berti, Windmann, and Schröger (2005, see also Bendixen, Roeber, & Schröger, 2007; Bendixen, & Schröger, 2008) showed that distraction is modulated by whether participants repeat a response from the previous trial or switch responses. A speculative account of this effect is that the occurrence of a change in the auditory context appears to bias the system towards a response switch, making response repetition more difficult and slower to achieve (see Schuch, & Koch, 2010, for converging evidence in a task switching task). Perhaps most illustrative of the involvement of complex mechanisms is the finding of post-deviance distraction, that is, longer RTs in the first standard trial following a deviant trial relative to the remaining standard trials (Berti, 2008a; Ahveninen, Jääskeläinen, Pekkonen, Hallberg, Hietanen, Näätänen, Schröger, & Sillanaukee, 2000; Kähkönen, Ahveninen, Pekkonen, Kaakkola, Huttunen, Ilmoniemi, & Jääskeläinen, 2002; Roeber et al., 2003). According to Roeber et al. (2003), this effect "may reflect an ongoing process of re-allocation of attention back to the task-relevant stimulus property after the occurrence of an attention-catching task-irrelevant deviation" (Roeber et al., 2003, p. 355; see also Berti, 2008a; Roeber et al., 2005). Such effect certainly suggests that deviants elicit some cognitive interference beyond the resolution of the trial in progress, reminiscent of what is observed in task switching studies (e.g., Meiran, Chorev, & Sapir, 2000; Roger, & Monsell, 1995; Koch, & Brass, 2013), but there is as yet no solid mechanistic account of post-deviance distraction. In a study exploring the determinants of the increase of deviance distraction in old age (Andrés et al., 2006; see also Berti, Grunwald, & Schröger, 2013; Getzmann, Gajewski, & Falkenstein, 2013), Parmentier and Andrés (2010) reported age-related increases in both deviance and post-deviance distraction but proportionally less so in the latter. We interpreted this finding as possible evidence of a greater number of age-sensitive processes at play in deviant trials (disengagement from distractors, see also Cashdollar, Fukuda, Bocklage, Aurtenetxe, Vogel, & Gazzaley, 2013, and reactivation of the relevant task set upon the presentation of the target stimulus) than in post-deviant trials (completion of task set reactivation). Interestingly, this view fits well with the finding of an age-related deficit in task preparation (Lawo, Phillip, Schuch, & Koch, 2012).

Deviance is not sufficient: the role of the task-irrelevant stimulus' informative value

It is commonly assumed that deviant sounds capture attention in an obligatory fashion and that deviance is a sufficient condition for the emergence of distraction (e.g., Escera et al., 1998). Yet past research using the cross-modal oddball task exhibits a specific methodological characteristic that authors overlooked. Parmentier, Elsley, and Ljungberg (2010) pointed out that in these studies the target stimuli always followed a to-be-ignored auditory stimulus and did so after a fixed temporal interval, such that irrelevant sounds arguably acted as unspecific warnings (that is, stimuli heralding the imminent presentation of the target without conveying information regarding their identity or the appropriate response; Drazin, 1961; Niemi, & Näätänen, 1981). Evidence of the warning value of the auditory stimuli is visible in the speeding of responses in the presence of that task-irrelevant sounds relative to a block of silent trials (Andrés et al., 2006; Parmentier, & Andrés, 2010), but a test of whether this warning information mediates deviance distraction was first reported by Parmentier, Elsley and Ljungberg in a modified cross-modal oddball task comparing three conditions. In the informative condition, all sounds were followed by a visual target (as in previous studies). In the uninformative condition, standard and deviant stimuli were followed by a target in half the trials only (a blank screen was used in the remaining trials), following one of three equi-probable time intervals. In this condition, therefore, the auditory stimuli did not predict whether or when targets would occur. Finally, in the informative deviant condition, the deviant sound was always followed by the target after a fixed temporal interval but the standard was not (making the deviant sound informative and the standard sound uninformative). Distraction was observed in the informative condition (replicating past work) but not when the sounds were uninformative (see Ljungberg, Parmentier, Leiva, & Vega, 2012; Wetzel, Widmann, & Schröger, 2012, for replications). Furthermore, relative to uninformative standard sounds, informative deviant sounds yielded facilitation instead of distraction. In sum, Parmentier et al. (2010) showed that (1) deviant sounds in the cross-modal oddball task yield behavioral distraction insofar as the auditory stimuli fulfill the function of unspecific warning signals, thereby gaining relevance for goal-directed behavior, and

(2) that variations in the balance of information provided by standard and deviant sounds can lead to distraction, no effect, or facilitation. Interestingly, recent work shows that while behavioral deviance distraction is abolished for uninformative auditory stimuli, the P3a response to these is undistinguishable from that observed in the informative condition (Wetzel, Schröger, & Widmann, 2013), suggesting that the mediation of behavioral distraction by the sound's information value originates from mechanisms posterior to and independent from the electrophysiological marker of involuntary orienting response towards novelty.

The results highlighted above indicate that auditory deviance is not sufficient for behavioral distraction to emerge. Instead, distraction is contingent upon the sounds warning the cognitive system of the imminent presentation of a target. The critical nature of the information provided by the task-irrelevant sounds is not entirely clear in these studies, however, for informative and uninformative conditions involved the simultaneous manipulation of temporal and event information. Put simply, temporal information corresponds to information about the target's time of occurrence while event information announces whether a target is likely to follow. The roles of these two types of information were orthogonally contrasted by Ljungberg et al. (2012) across four conditions. In the Event + Temporal Information condition, every auditory stimulus was followed by a visual target stimulus after a fixed temporal interval. In the Uninformative condition, auditory stimuli were followed by a visual target stimulus or a fixation cross with equal probabilities, following a variable temporal interval. In the Event Information condition, auditory stimuli always announced the imminent presentation of a visual target stimulus but following a variable temporal interval. In the Temporal Information condition, auditory stimuli were followed by a visual target stimulus or a fixation cross with equal probabilities but following a fixed temporal interval. The results were unambiguous: distraction was observed whenever event information was present and not otherwise. Temporal information, in contrast, had no impact. These findings suggest that preparation for action is a key goal for the cognitive system and that deviance only translates in behavioral distraction when task-irrelevant stimuli serve that goal. One could argue that event information might play an important role because it is especially relevant to assess the cost–benefit ratio of preparing for action (it is beneficial to prepare for action if one knows that the target is about to be presented, but much less so if preparation is useless half the time) while temporal information, at least for the small variation in intervals we used, is of little relevance (if the systems knows the target is coming, it makes sense to prepare regardless of whether the target is coming in 150, 250 or 350 ms). Finally, it should also be pointed out that the presence or absence of the target is arguably more salient than the specific interval between the auditory stimulus and the visual target, which might also have contributed to limit the impact of temporal information.

One theoretically important question is whether the effect of task-irrelevant information described above can be generalized from the cross-modal oddball task to an auditory oddball task in which deviant and target information are integrated into the same stimulus (e.g., Berti, & Schröger, 2003). I would argue that task-irrelevant and target information in auditory oddball tasks maintain a relationship that can be described as conveying event and, in some studies, temporal information. Let us consider the task most commonly used in auditory oddball task: the duration judgment task. Participants in that task are asked to judge the duration of sounds in a two-forced choice categorization task (short vs. long) irrespective of rare changes in pitch. Because the pitch information is available from the onset of the sound, and the point in time at which the sound can either stop (short) or continue (long) always follows the sound's onset by a fixed interval, the irrelevant feature (pitch) arguably provides both temporal and event information about the target feature (duration). Li, Parmentier, and Zhang (2013) examined this issue further and confirmed that the vast majority of past auditory oddball studies used stimuli affording event information and, on many occasions, temporal information. Over 70 % of studies used the duration discrimination task described above. In the remaining studies, the task-irrelevant stimulus or feature always preceded the target, typically within the same auditory object (Hölig, & Berti, 2010; Horváth, Roeber, Bendixen, & Schröger, 2008; Roeber, Berti, Müller, Widman, & Schröger, 2009; Schröger, 1996; Wetzel, Berti, Widmann, & Schröger, 2004; Wetzel, Widmann, & Schröger, 2009), with two exceptions: one study where irrelevant and target occurred simultaneously (Rinne, Särkkä, Degerman, Schröger, & Alho, 2006), and another in which deviance (duration) occurred after the target (location; Roeber et al., 2003). In order to establish whether behavioral distraction in the auditory oddball task is mediated by event information in the same way as in the cross-modal oddball task, Li et al. (2013) replicated the design of Ljungberg et al. (2012) but using a task in which participants categorized the lateral movement of a sound while ignoring rare and unexpected changes of its identity (bee vs. frog sound). Each sound started from a central location. Event and temporal data were manipulated by fixing or varying the probability that a sound would move (1 vs. .5) and, if it did, when the movement onset would occur (100, 200 or 300 ms after sound onset). The results revealed that distraction was observed as long as the presentation of the irrelevant feature announced an upcoming

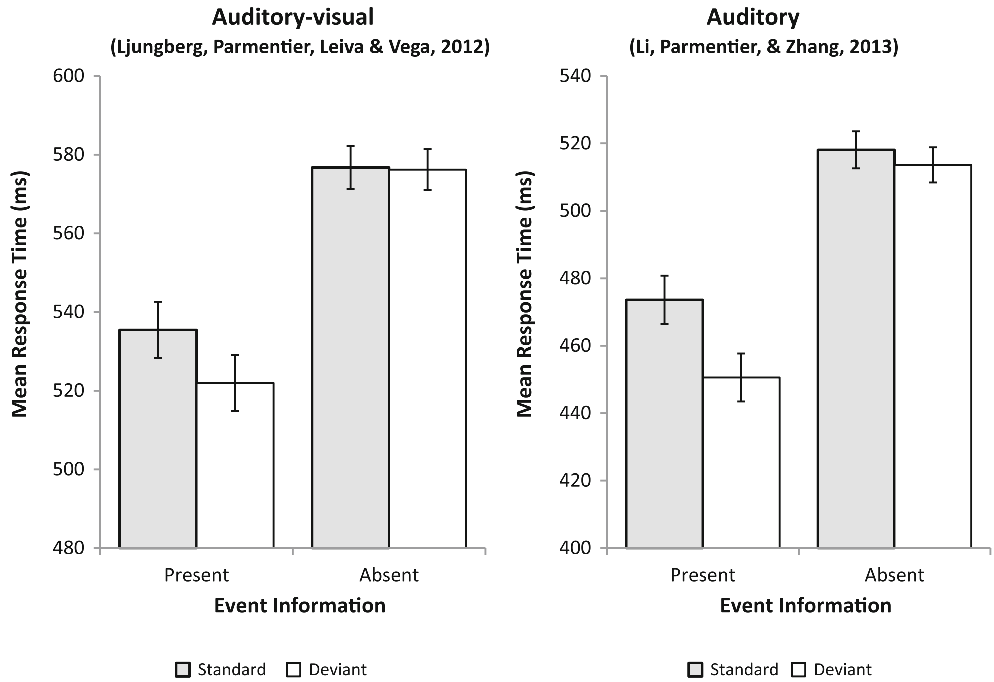

Fig. 2 Illustration of the role of event information in deviance distraction. The figure presents mean response times adapted from an auditory–visual oddball task (Ljungberg et al., 2012, digit categorization task, $n = 80$) and an auditory oddball task (Li et al., 2013, movement discrimination task, $n = 80$). The data presented were compiled to contrast conditions with and without event information. Deviance distraction was observed when distractors conveyed event distraction (distractors always announcing a target) and not when they did not (distractors followed by a target in 50 % of trials only)

target (event information) regardless of its temporal characteristics. As visible from Fig. 2, the results mimicked almost perfectly those found in the cross-modal oddball task by Ljungberg et al. (2012), thereby highlighting further the task-irrelevant stimulus' informational value as a potent mediator of behavioral deviance distraction.

In summary, out of the 61 auditory oddball studies I am aware of in which the informative value of the task-irrelevant sounds was not manipulated: 59 used tasks in which the task-irrelevant feature arguably conveyed event information about the target, one reported behavioral distraction with both presented simultaneously (Rinne et al., 2006) and one concluded that a weak behavioral distraction effect is observed in a location judgment task where deviance is conveyed by duration (Roeber et al., 2003; note however that this effect was, as noted by the authors, weaker than when participants judged the duration while ignoring location deviants, and that no direct statistical test was reported confirming the significance of that weak effect). In the six more recent studies in which the information yielded by the task-irrelevant stimuli was manipulated, behavioral distraction systematically disappeared when distractors did not convey event information (Li et al., 2013; Ljungberg et al., 2012; Parmentier et al., 2010; Parmentier, Turner, & Perez, 2013; Wetzel et al., 2012, 2013). The role of event information may also apply to other tasks. For example (Hughes, Vachon & Jones, 2005, 2007; Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013) reported a reduction in serial recall performance when a deviant sound is inserted between two items from a visually presented to-be-remembered sequence of verbal stimuli (see also Ljungberg, Parmentier, Hughes, Macken, & Jones, 2012). In these studies too, auditory stimuli were always followed by a target and therefore provided event information. Finally, the notion of event information also provides a parsimonious explanation of a facilitation effect that SanMiguel et al. (2010) attributed to an arousing effect of novel sounds in long-duration trials (see Parmentier et al., 2010, for a discussion).

The modulation of behavioral deviance distraction by the informational value of the task-irrelevant sounds fits well with Schröger's (1997) proposition that distraction depends on an interaction between the magnitude of deviance (e.g., Schröger, 1996) and a variable threshold. More specifically, one could argue that the threshold may be lowered when the auditory stimuli fulfill a useful function by conveying event information (which, as I argued earlier, is the case in the vast majority of auditory–visual and pure auditory oddball tasks). The relationship between event information and a threshold mediating the link between MMN and P3a is less convincing, however, because recent evidence reported that these responses are not affected by the informational value of the irrelevant sounds while behavior is (Wetzel et al., 2013). Hence, the threshold or filtering mechanism responsible for the mediation of *behavioral* distraction by the sounds' informational value must be a late one, posterior to the mechanisms underpinning P3a.

Finally, the findings that deviance distraction is mediated by the sound's value as an unspecific warning (e.g., Parmentier et al., 2010) and that both standard and oddball sounds yield faster response times than in silent trials (when the latter are presented in a separate block, Andrés et al., 2006) highlight that distraction might reflect both a detrimental effect of the deviant stimuli as well as a potential facilitation by the standard stimuli. Although the issue has received little attention, Jankowiak and Berti (2007) suggested it may be the case based on data from an auditory duration discrimination task in which three types of deviant sound (location, pitch, intensity presented in random order across the task) occurred following one, two or three standard sounds (manipulated between participants). These authors reported a shortening of RTs in the standard condition as the number of standard sound preceding a deviant sound increased (from 392 to 374 ms), while RTs in the deviant condition increased correspondingly (from 388 to 413 ms). A note of caution is warranted, however, since the regular arrangement of the standard and deviant conditions in that study made it possible for participants to anticipate the standard sounds. Data from a MMN study by Haenschel, Vernon, Dwivedi, Gruzelier, and Baldeweg (2005) provide some support to the notion of facilitation by standard sounds, as they reported an increase in a slow (50–250 ms) repetition-induced positive wave for standard sounds as the number of preceding standard sounds increased (2, 6, 36). The authors concluded that this positive response might underpin the formation of a sensory representation of the standard sound. The recent study by Berti (2013) might provide the best evidence of the interplay between the effect of the deviant and that of the standard sounds. This author compared distraction in rare and frequent conditions where the rare sounds consisted of novel sounds while the remaining trials involved a standard tone (oddball task) or no sound (distractor task). The data showed a reduction of RTs in response to standard sounds compared to silent trials, thereby indicating that the repetition of the standard sound does indeed benefit performance. However, and importantly, novel sounds yielded longer response times in both tasks, demonstrating that novel sounds induce distraction even in the absence of a standard sound (interestingly, P3a and RON were found in both tasks while MMN was observed in the oddball task and an enhanced N1 response was observed in the distractor task). Interestingly, however, the distraction effect (difference in RT in the frequent and rare conditions) was greater in the oddball task than in the distractor condition, suggesting that distraction in the oddball task involved some facilitation by standard sounds against which deviant sounds generated greater distraction.

Violations of predictions underpin deviance distraction

The previous section aimed to demonstrate that deviance is not sufficient for behavioral distraction to occur. This section aims to show that deviant sounds yield distraction because they violate predictions rather than because they are rare. The starting point of this thesis is the distinction between rarity and unexpectedness, which most research articles manipulating deviance through rare physical changes have bundled up indiscriminately in their definition of a deviant sound. If indeed true that deviant sounds are typically both rare and unexpected, these characteristics can be distinguished. To use an analogy, a full eclipse of the moon is rare but perfectly predictable. Hence one may wonder what between rarity and unexpectedness, if not both, may be critical in inducing behavioral distraction. To help distinguish between the two, let us contrast two general hypotheses of distraction: the base-rate probability hypothesis and the unexpectedness hypothesis. Low base-rate probability, or rarity, has traditionally been a key defining feature of oddball stimuli. One idea permeating most oddball studies of novelty detection is that the repeated presentation of the standard sound results in the building up of a neural model with which incoming stimuli are compared (e.g., Näätänen, 1990; Schröger, 1997). When this incoming stimulus is rare, its clash with the neural model triggers the detection of change and the involuntary capture of the participant's attention. This trace-mismatch view is a prominent explanation of MMN (see Näätänen, & Winkler, 1999, for a review). Extrapolated to the measurement of behavioral performance, the base-rate probability hypothesis posits that any sound of low base-rate probability, presented in the context of another (frequent) sound, should yield distraction. In contrast, the unexpectedness hypothesis posits that oddball sounds capture attention because they violate the cognitive system's predictions about upcoming events. That is, in a task in which most auditory stimuli are standard ones, the system quickly learns to predict standard sounds. Deviant sounds violate that prediction. The violation of predictions is increasingly emerging as a potent alternative to the trace-mismatch account of MMN (Winkler, 2007). In line with this view, unexpected stimulus omissions elicit MMN (e.g., Yabe, Tervaniemi, Reinkainen, & Näätänen, 1997), as does the violation of incidentally learned rules about perceptual transitions (Schröger, Bendixen, Trujillo-Barreto, & Roeber, 2007; Van Zuijen, Simoens, Paavilainen, Näätänen & Tervaniemi, 2006). According to the unexpectedness hypothesis, an irrelevant sound should distract participants in the cross-modal oddball task whenever it violates the cognitive system's predictions, irrespective of whether that sound is rare or not.

A systematic contrast between the two above hypotheses was reported by Parmentier, Elsley, Andrés, and Barceló (2011) in a study where standard and deviant trials of the cross-modal oddball tasks were carefully arranged to ensure that deviant trials most often (but not always) occurred on two successive trials. This manipulation allowed us to contrast base-rate probability and predictability orthogonally. Compared to the baseline of predictable standard trials, distraction was observed not only for unexpected deviant sounds (as in past studies) but also for unexpected standard sounds (i.e., when a deviant trial was not followed by a second deviant trial but, instead, by a standard trial). Furthermore, deviant sounds yielded no distraction when they were expected. Hence, deviance distraction did not occur because deviant sounds were rare but because they violated the cognitive system's predictions (Bendixen et al., 2010; Bendixen, & Schröger, 2008; Berti, 2012; Nöstl, Marsh, & Sörqvist, 2012; Schröger et al., 2007, for converging conclusions).

Strong evidence that the violation of predictions captures attention comes from studies reporting distraction (measured electrophysiologically and/or behaviorally) in response to violations of a rule rather than to rare physical changes in the stimuli. For example, MMN is observed for repetitions among a sequence of otherwise alternating tones (Nordby, Roth, & Pfefferbaum, 1988). Bendixen, Prinz, Horváth, Trujillo-Barreto, and Schröger (2008) showed, in a passive condition, a deflection of MMN for violations of a more complex rule associating the frequency of a tone to the duration of the previous (see also Paavilainen, Simola, Jaramillo, Näätänen, & Winkler, 2001; Schröger et al., 2007). Finally, evidence indicates that the cognitive system is able to extract and process more than one rule at a time (Bendixen et al., 2007; Costa-Faidella, Grimm, Slabu, Díaz-Santaella, & Escera, 2011; Winkler, & Czigler, 1998), including ones relating to adjacent (local rule) and non-adjacent (global rule) sounds (Bendixen, Schröger, Ritter, & Winkler, 2012; Horváth, Czigler, Sussman, & Winkler, 2011).

In sum, the evidence available to date indicates that distraction occurs as a result of the conflict between a stimulus and internally generated predictions, or more generally speaking, when task-irrelevant stimuli trigger surprise (see Itti, & Baldi, 2009, for a formal definition of surprise). The cognitive system extracts stimulus regularities, sometimes complex, and uses these to build forward models (Bendixen, SanMiguel, & Schröger, 2013; Bendixen, Schröger & Winkler, 2009; Bubic, von Cramon, Jacobsen, Schröger, & Schubotz, 2008; SanMiguel, Widmann, Bendixen, Trujillo-Barreto, & Schröger, 2013; Wacongne, Changeux, & Dehaene, 2012) allowing the world around us to be simplified and the deployment of attention to be regulated in an efficient manner, triggering an attentional shift when stimuli violate predictions and not otherwise (e.g., Bendixen et al., 2009; Horváth et al., 2011; Schröger et al., 2007; Paavilainen, Arajärvi, & Takegata, 2007; Winkler, 2007).

Since past work typically relied on paradigms in which regularities were acquired implicitly by participants (e.g., Bendixen, & Schröger, 2008; Haenschel et al., 2005), one can reasonably argue that the building of predictions and their evaluation against new incoming stimuli occurs below the threshold of consciousness. Taken together these studies show not only that distraction occurs when sequential rules are violated (e.g., Bubic et al., 2008; Schröger et al., 2007) but also that it is abolished for rare deviants when these can be predicted based on implicit probability learning. The latter point naturally leads to a new question: can distraction also be abolished when deviants are *explicitly* predicted (e.g., by a cue)? This issue is addressed in the next section.

Cognitive control and deviance predictability

There is no doubt that the orientation of attention to an unexpected event is a fast and involuntary response. One may therefore assume that such phenomenon should not be subject to top-down control. Yet some work suggests that behavioral distraction (and in some studies the P3a response) is eliminated or reduced when participants are given explicit cues to prepare for these sounds. The first study to show so was reported by Sussman, Winkler and Schröger (2003), who asked participants to discriminate between short (100 ms) and long (200 ms) tones that occasionally varied in pitch. Each sound was preceded by a visual stimulus consisting of a colored square. In the unpredictable condition, the square's color and the sound condition (standard or deviant) were independent from each other. In the predictable condition, they were correlated, such that one color announced the presentation of the deviant tone while another announced the standard tone. Behavioral distraction was observed in the unpredictable condition but was eliminated in the predicable one, suggesting that distraction is modulated by top-down control. Using a similar task, Wetzel, and Schröger (2007) also reported a reduction of distraction in the predictable condition in children and adolescents. The same results also emerged with novel sounds in a study requiring children and adults to judge whether sounds emanating from a central location moved left or right (Wetzel et al., 2009). Horváth, Sussman, Winkler, and Schröger (2011) further showed that cues can reduce distraction by allowing the system to prepare for a specific type of deviant or for deviance in general, suggesting that cognitive control can be exerted through two mechanisms: one minimizing the impact of stimulus-specific features and one of a more general nature reducing distractibility at a more abstract level. Horváth, and Bendixen (2012) suggested that the reduction of distraction by cues in past studies might not have reflected actual cognitive control but, instead, different cue processing strategies (participants allocating processing resources to cues in a condition where they are always valid and much less in a condition when they are always uninformative). To examine this issue, the authors used cues that were valid in 80 % of trials, thereby ensuring that valid and invalid cues benefited from the same amount of processing. Valid cues reduced distraction relative to invalid cues, leading the authors to conclude that "distraction is prevented by means of preparatory processes initiated by the cues, and it is not the byproduct of a between-condition information processing load difference" (p. 347). Finally, Parmentier, and Hebrero (2013) further confirmed that the abolition of behavioral distraction by explicit deviance cues appears to reflect cognitive control and not simply the division of attention between the processing of the cues and the orientation to deviance. We asked participants to judge the direction in which the sound of a bee moved (left or right), with the bee sound changing pitch on rare and unpredictable trials. We observed distraction in the control condition where visual stimuli presented ahead of the target sound did not announce whether the latter would be the standard or the deviant sound. When the color of these visual stimuli warned participant of the type of upcoming sound, no distraction was observed. Importantly, this was true regardless of whether the cue preceded the target sound by 250 ms or by 2250 ms (the latter arguably allowing participant to finish processing the cue and its meaning before the sound's presentation).

Altogether, the evidence suggests that cues announcing the presentation of a deviant stimulus reduce behavioral deviance distraction through top-down control and not due to differential cue processing. The consistent finding that these cues do not affect the N1/MMN complex but do modulate P3a and RON corroborates the view that their modulation of distraction occurs beyond the stage of sensory filtering.[2]

The involuntary semantic processing of deviant sounds and its behavioral aftermath

Evidence from electrophysiological studies suggests that attention capture by oddball sounds is modulated by the content or meaning of these sounds, in turn indicating that they undergo some level of automatic semantic processing (e.g., Czigler, Cox, Gyimesi, & Horváth, 2007; Frangos, Ritter & Friedman, 2005; Roye, Jacobsen, & Schröger, 2007). Electrophysiological markers of this processing suggest that it starts a few hundred milliseconds following the sound's onset and regardless of whether participants attend it or not (Shtyrov, Hauk, & Pulvermüller, 2004; Frangos et al., 2005). Several examples can be found in the literature, from a modulation of the MMN response by a novel sound's sexual connotation (Frangos et al., 2005), the variation of the P3a response as a function of the sound's identifiability (Escera et al. 2003) or aversive emotional valence (Czigler et al., 2007), to the reduction of the P3a response to a deviant word (e.g., "duck") when its meaning is primed by another deviant stimulus consisting of its associated sound (e.g., "quack"; Friedman, Cycowicz, & Dziobek, 2003; see also Horváth, Winkler, & Bendixen, 2008, for the proposition that such semantic effect might modulate P3a because this response reflects processes evaluating the significance of events). Importantly, the analysis of an auditory stimulus' semantic content is, within that field of research, assumed to be contingent upon its prior detection as novel or deviant stimulus (e.g., Shtyrov et al., 2004) and/or the involuntary orientation of attention towards it (Escera, Yago, Corral, Corbera, & Nuñez, 2003).

In order to examine whether the semantic appraisal of deviant sounds impacts on behavior, I modified the cross-modal task and manipulated the relationship between the deviants' and the targets' meaning (Parmentier, 2008). Participants categorized visual arrows pointing left or right presented immediately after to-be-ignored standard tones or, on rare and unpredictable trials, spoken word deviants "left" or "right" (either congruent or incongruent with the upcoming target). The results showed that incongruent deviant sounds disrupted performance more than congruent ones (semantic effect) while both types of deviants delayed responses compared to the standard sound (deviance distraction)—see Fig. 1 for an illustration of the method and aggregated plot of the result. The results suggested that deviance distraction resulted from the time penalty yielded by the involuntary orientation of attention to and away from deviant sounds (Parmentier et al., 2008) while the semantic effect reflected a conflict between the activation of lexico-semantic and action-related networks yielded by the involuntary processing of deviants on the one hand, and competing activations brought forth by the voluntary processing of the targets on the other hand. I argued that deviance distraction triggers the involuntary semantic analysis of the deviant and that the semantic analysis of the latter, once initiated, follows its independent course. This contention is supported by the finding that deviance distraction, but not the semantic effect, (1) reduces with task

[2] I thank János Horváth for pointing this out during the review process.

practice, and (2) increases as the number of dimensions (acoustics, lexicality, source) differentiating the standard from the deviant sound increases. Further work by Parmentier, Turner, and Elsley(2011) helped establishing a double dissociation between deviance distraction and the semantic effect by showing that the semantic effect, but not deviance distraction, increased when more time was available for sound-related semantic activations to build up prior to the appearance of the visual target.

The semantic effect can arguably been construed as the resolution of a conflict between competing activations and/or response codes (Botvinick, Cohen, & Carter, 2004; Melcher, & Gruber, 2009), conflict that appears to require the inhibition of the network activated by the deviant sound in favor of the selection of that related to the target (Parmentier et al., 2011), in much the same way as conceptualized in other paradigms involving cross-talk interference (e.g., Bush, Whalen, Roden, Jenike, MacInerney, & Rauch, 1998; Fan, Flombaum, McCandliss, Thomas & Posner, 2003; Fan, Kolster, Ghajar, Suh, Knight, Sarkar, & McCandliss, 2007; Macdonald, Cohen, Stenger, & Carter, 2000; Melcher & Gruber, 2009; Ullsperger, & von Cramon, 2001; Van Veen & Carter, 2005; Yeung, Botvinick, & Cohen, 2004), and akin to findings from negative priming studies (Buchner, Zabal, & Mayr, 2003; May, Kane, & Hasher, 1995; Mayr, & Buchner, 2007) or the inhibition of S-R mappings (e.g., Kiesel, Kunde, & Hoffman, 2006; Kunde, 2003).

While the framework depicted above is coherent, the notion that the semantic effect follows from the orienting of attention toward the task-irrelevant sound by virtue of its novelty or deviance requires further qualification. Indeed there are numerous examples of distractor-target conflict effects in conditions where the task-irrelevant stimuli, or the conflict they bring about, do not constitute oddball stimuli or events. For example, compatibility effects have been found when incongruent distractors are presented in separate blocks of trials or dominate the task, whether in the Stroop task (Bugg, Jacoby, & Toth, 2008; Kane & Engle, 2003; see Elliott, Cowan and Valle-Inclan, 1998; Hanauer, & Brooks, 2003; Roelofs, 2005, for evidence from an auditory–visual version of the Stroop task), the Simon paradigm (e.g., Melara, Wang, Vu, & Proctor, 2008), the flanker task (e.g., Tilman, & Wiens, 2011), the size congruity task (e.g., Santens & Verguts, 2011) or directional cuing tasks (e.g., Ho, & Spence, 2006). An elegant cross-modal Stroop study by Elliott, and Cowan (2001) provides a clear hint that interference from to-be-ignored auditory distractors may have two origins. These authors found that Stroop interference decreased but did not disappear as the same auditory distractor was repeated across five incongruent trials and that interference increased significantly when a repeated incongruent spoken color name was replaced by another. These findings can be viewed as an indication that task-irrelevant auditory stimuli may undergo involuntary semantic processing at two levels: one resilient to habituation (akin to Stroop interference when incongruent stimuli are expected or presented in pure blocks; e.g., Kane, & Engle, 2003; Tilman, & Wiens, 2011), and one that may follow deviance distraction (Parmentier, 2008). Capitalizing on the finding that deviance distraction can be switched off by rendering the auditory stimuli uninformative (Parmentier et al.,2010), Parmentier, Turner, and Perez (2013) used the arrows cross-modal oddball task (Parmentier, 2008) to compare the semantic effect in the presence and in the absence of deviance distraction. In line with past findings (Parmentier et al., 2010; Wetzel et al., 2012), deviance distraction was abolished when the irrelevant sounds conveyed no event information. Most importantly, however, the semantic effect was reduced but not eliminated by this manipulation. We interpreted this finding as evidence that spoken deviant sounds elicit automatic semantic processing through two routes: one independent from the orienting of attention toward these sounds by virtue of their deviance and, in line with Parmentier's (2008) model, and one contingent upon this orienting response that amplifies semantic processing significantly. Finally, it is worth noting that while the evidence described above relates to cases where target and deviant clash with respect to semantics, some evidence suggest that semantic aspects of the deviants stimuli can impact on behavior through other mechanisms too. Indeed, Ljungberg, and Parmentier (2012a) recently showed that word deviants spoken urgently, while yielding distraction, do so less than calmly spoken words, which we interpreted as evidence that the urgency conveyed by the words' intonation primed the cognitive system to speed the production of responses.

Behavioral distraction distinct from electrophysiological measures

The study of behavioral deviance distraction has strong historic ties to the electrophysiological literature, in which longer response times and reduced response accuracy were first reported and typically regarded as the consequence of the cognitive processes underpinning MMN, P3a and RON. From many of these studies, one may be left with the impression that behavioral distraction is a direct consequence of these responses. Such impression is probably simplistic, however, for increasing evidence indicates that electrophysiological and behavior measures of distraction, if often observed together, do not correlate. For example, behavioral distraction can vary widely in the absence of variation in the P3a response. Indeed, Wetzel et al. (2013)

reported that wiping out behavioral distraction by making the task-irrelevant sounds uninformative (Parmentier et al., 2010) does not affect P3a, which led the authors to argue that both informative and uninformative deviant sounds capture attention and undergo some involuntary evaluation but that the latter only translates into behavioral distraction if the task-irrelevant stimuli predict the occurrence of a target stimulus. Another example can be found in a study by SanMiguel, Morgan, Klein, Linden, and Escera (2010) in which deviant sounds could result in performance facilitation while exhibiting the same pattern of electrophysiological responses as observed when deviant sounds elicit distraction. Other studies found the opposite relationship between P3a and behavior, namely variations in P3a in the absence of behavioral effects. For example, Horváth, Czigler, Birkás, Winkler, and Gervai (2009) reported large variations in P3a and RON between young and older adults, and variations in RON when comparing children and young adults, but in both cases in the absence of differences in a behavioral measure of distraction. Berti (2012) observed a more pronounced P3a response for novel compared to deviant sounds while both yielded equivalent levels of behavioral distraction. Significant MMN and P3a responses were also observed in the absence of any behavioral distraction by Jankowiak and Berti (2007) in a condition in which pitch, location and intensity deviants made up 50 % of stimuli in a duration judgment task. Finally, Getzmann et al. (2013) found no correlation between behavioral distraction and MMN, P3a or RON in young adults.

The evidence above suggests that behavioral deviance distraction is not a mere byproduct of the electrophysiological markers of distraction (MMN, P3a, RON) but, instead, appears to be governed by further, and presumably later, mechanisms. On the other hand, the observation of behavior does not allow one to assume the existence of differences in these responses either. A key challenge facing the development of an integrated model of deviance distraction will be to account for this discrepancy and identify the cognitive mechanisms able to modulate behavioral distraction beyond MMN, P3a and RON.

Outstanding questions and avenues for future research

While some progress has been achieved in understanding the underpinnings of behavioral deviance distraction, a number of interesting empirical findings will require more research before their theoretical implications can be fully ascertained. An exhaustive list would be too long to develop here, so I highlight a few. For example, some evidence suggests a relationship between deviance distraction and working memory. Indeed, P3a and behavioral distraction have been found to decrease in oddball tasks involving a memory load (e.g., Berti, & Schröger, 2003; SanMiguel, Corral, & Escera, 2008) or when task instructions increase in complexity (Parmentier et al., 2008, Experiment 2). This explanation proposed for this effect is that a memory load decreases distraction by mobilizing resources that would otherwise be used to shift of attention to a deviant stimulus. Such explanation relies on the assumption, so far not tested, that the cognitive system prioritizes the maintenance of the load over the involuntary orientation of attention toward unexpected stimuli. Whether the mechanism responsible for biasing attention in that way is related to those underpinning cognitive control (e.g., Horváth, & Bendixen, 2012) constitutes an interesting question that would warrant further investigation.

The finding that deviance distraction is stronger for response repetition than response switch (Bendixen et al., 2007; Bendixen, & Schröger, 2008; Roeber et al., 2005) is another empirical finding that may deserve further theoretical scrutiny. The current explanation of this effect is that deviant sounds bias the cognitive system towards change (the rationale being that if the auditory context changes it is unlikely that the previous action will remain appropriate), thereby facilitating response switch and hindering response repetition. This hypothesis generates more questions than it answers, however. To start with, how reliable is the effect? Is it observed in all modalities and task variations? Is the bias toward change or against repetition? Is the bias general (facilitating the production of any response other than that produced on the previous trial) or specific to cases where only two response options are part of the task set (which is the case in the vast majority of studies) and therefore, arguably, strongly inhibiting each other?

While part of the research on deviance distraction has sought to establish its cognitive inner workings, some work has focused on more general variables such as aging or, more recently, the impact of the participants' emotional state. While some studies reported that deviance distraction increases with aging in the auditory–visual oddball task (Andrés et al., 2006; Parmentier, & Andrés, 2010), the exact origin of this effect remains unclear. Furthermore, results from purely auditory tasks are discrepant, with some reporting equivalent distraction effects in young and older adults (Getzmann, Gajewski, & Falkenstein, 2013; Horváth et al., 2009; Mager, Falkenstein, Störmer, Brand, Müller-Spahn, & Bullinger, 2004) while Berti et al. (2013) observed a larger distraction effect in older adults. It remains unclear through which mechanisms and under which conditions aging mediates distraction. A similar observation can be made of the recent work reporting that distraction is also sensitive to emotional manipulations and increases when negative pictures are interspersed among trials of the cross-modal oddball task (Domínguez-Borràs, Garcia-Garcia, & Escera, 2008) or when sadness is induced prior to the oddball task (Pacheco-Unguetti & Parmentier, 2013). One putative explanation proposed by Pacheco-Unguetti and Parmentier is that emotions consume cognitive resources (perhaps by eliciting ruminative thoughts) that are therefore not available to disengage attention from the deviant stimuli. An alternative explanation might be that negative affect increases our receptivity to distractors (e.g., Gross, 1998; Lazarus, 1991) or motivate us to process information in a more vigilant way (e.g., Bodenhausen, Gabriel, & Lineberger, 2000).

Just as factors increasing distraction (aging, emotions) would warrant further work, understanding the mechanics of positive effects such as that of cognitive control would also contribute to develop a more integrated model of deviance distraction. Several studies have shown that providing participants with cues allows them to reduce or eliminate distraction by deviant stimuli (e.g., Sussman et al., 2003; Wetzel et al., 2009) and that this effect is unlikely to reflect the allocation of attention to cue processing (Horváth, & Bendixen, 2012; Parmentier, & Hebrero, 2013). Yet I would argue that the proposition that participants use cues to prepare for the deviant stimulus is not truly an explanation. What is meant by "to prepare"? Should we really assume that it involves some sort of controlled top-down mechanism? Or could the effect of the cues simply be to take away the unpredictability of the deviant stimulus (as can be achieved through implicit learning of stimulus transitional probabilities; e.g., Parmentier et al., 2011)?

Finally, it may be theoretically useful to expand research on deviance distraction by examining its possible relationship to other fundamental cognitive effects. Recent work on post-error slowing provides a good example. It is well established that response times increase following the production of an error (Jentzsch, & Dudschig, 2009; Laming, 1979; Rabbitt, 1966). This effect has traditionally been interpreted as the sign of some post-error adjustment mechanism (e.g., Botvinick, Braver, Barch, Carte, & Cohen, 2004; Li, Huang, Yan, Paliwal, Constable & Sinha, 2008). This view was recently challenged by the suggestion that slowing does not occur because of the prior production of an error per se but because errors are unexpected events (Notebaert, Houtman, Van Opstal, Gevers, & Verguts, 2009). The cogent part of these authors' thesis was the demonstration that slowing can actually be observed after correct responses (post-*correct* slowing) in a context where participants expect to produce errors (see Nuñez-Castellar, Kühn, Fias, & Notebaert, 2010, for a replication and evidence of parallel effects in response times and the P3 response; and see Wessel, Danielmeier, Morton, & Ullsperger, 2012, for evidence of a common neuronal architecture underpinning post-error slowing and novelty detection). Beyond what such findings may teach us about the mechanisms underpinning certain cognitive effects, I think they pose a more fundamental question: could the effect of stimulus unexpectedness have been overlooked in other psychological phenomena? For example, could deviance distraction play a role in Stroop-like interference effects? It is well established that Stroop-like interference increases as the proportion of incongruent trials decreases in mixed lists. This effect has typically been explained by goal neglect, that is, the failure to deploy inhibitory capabilities (in the case of the Stroop task, the increasing failure to inhibit the more automatic task—word reading—as the proportion of trials where both word reading and color naming lead to the same response increases; e.g., Kane, & Engle, 2003; Tillman, & Wiens, 2011). An alternative explanation, so far not examined, could be that incongruent trials become, as their frequency decreases, more unexpected and therefore slow responses or augment errors because they increasingly constitute potent oddball stimuli. This effect may even be stronger considering that deviant stimuli undergo enhanced semantic processing (Parmentier et al., 2013). In sum, an effect typically attributed to goal neglect might in fact reflect the impact of deviance distraction. More generally, it may be important to assess the extent to which deviance distraction may play a role in paradigms in which stimuli from a specific condition, or the interference they evoke, fulfill the characteristics of oddball events (namely that they violate predictions).

In conclusion, further work is required not only to (1) better ascertain what the cognitive underpinnings of some of the effects highlighted above are but also, more generally, to (2) develop a model of behavioral deviance distraction in which the cognitive processes involved posterior to the P3a and RON mechanisms can be identified, understood and modeled; and (3) to establish more systematically the extent to which deviance distraction may contribute to other documented cognitive phenomena.

Conclusion

Unexpected changes in an otherwise repeated or structured sequence generate behavioral distraction. Testament to the fundamental nature of behavioral deviance distraction, it is observed with auditory, visual and tactile task-irrelevant stimuli. On the basis of the evidence available to date, the functional mechanisms at play seem coherent across modalities. Behavioral distraction occurs when a sound violates the cognitive system's predictions as long as this sound is presented as part of a stream of task-irrelevant stimuli conveying event information about the target. In such circumstances, attention orients to and away from the unexpected deviant stimulus, triggering the involuntary processing of its semantic features and destabilizing the maintenance of the relevant task set. The outcome of this processing can linger in immediate memory long enough to interact with the processing of the target, increasing distraction when deviant and target are incompatible, reducing it when they are compatible. While involuntary, deviance distraction is nevertheless subject to top-down modulation insofar as it is abolished when deviants are expected, when attentional resources are not available to be deployed toward the deviant, and when task-irrelevant stimuli are uninformative and do not assist goal-directed behavior. On the other hand, deviance distraction increases in old age (at least in the cross-modal oddball task), or when participants experience strong emotions (such as sadness). These effects might possibly result from a reduction in the orientation of attention towards deviance (especially in conditions reducing P3a), but also a difficulty in disengaging attention from the deviant and reactivating the relevant task set. Increasing evidence indicates that behavioral deviance distraction is not the mere byproduct of the MMN/P3a/RON responses and appears to derive from distinct, high-level, and later mechanisms. This undoubtedly commands further investigation to develop a theoretical model able to account for the range of effects exhibited by behavioral distraction.

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