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Distraction and Facilitation – Two Faces of the Same Coin?

Nicole Wetzel*, Andreas Widmann, and Erich Schröger

Institute of Psychology, University of Leipzig, Leipzig, Germany

Abstract

Unexpected and task-irrelevant sounds can capture our attention and may cause distraction effects reflected by impaired performance in a primary task unrelated to the perturbing sound. The present auditory–visual oddball study examines the effect of the informational content of a sound on the performance in a visual discrimination task. The informational content was modulated by varying the sound–target interval and the probability of target occurrence. Effects of informational content were examined with two types of distractors: a burst of white noise (deviant) and environmental sounds (novel). Behavioral results reveal the following. (1) Novel and deviant sounds do not necessarily cause behavioral distraction effects when they are uninformative with respect to both time and probability of occurrence of a visual target. (2) Novel, but not deviant, sounds cause an unspecific bias toward facilitation. (3) The informational content of task-irrelevant sounds speeds reaction times, indicating the use of information not directly related to the task for enhancing performance. (4) It is suggested that performance in deviant and novel trials is the sum of the costs of attentional orienting and benefits of information as well as benefits of unspecific activation for novels.

Keywords

distraction, novelty, attention, orienting, information

Introduction

It is an essential function of attention to detect new events outside of the current attentional focus and to prepare the organism to react to these changes adequately. Because of the necessity to check whether a reaction is required, such attention-catching events (distractors) often cause impaired performance in an ongoing task that is not related to the distractor (termed the distraction effect; e.g., Berti & Schröger, 2006; Escera, Alho, Winkler, & Näätänen, 1998; Parmentier, Elsley, & Ljungberg, 2010; Schröger & Wolff, 1998; Wetzel, Widmann, Berti, & Schröger, 2006). However, recent studies have reported, under certain conditions, no impairment or even an improvement in a primary task when a task-irrelevant distractor appears (Parmentier et al., 2010; Ruhnau, Wetzel, Widmann, & Schröger, 2010; SanMiguel, Linden, & Escera, 2010). The present study examines which factors affect performance during the processing of task-irrelevant distractor sounds. In an auditory–visual oddball paradigm, we varied the informational content of distractor sounds regarding the onset time of target appearance and probability of visual target occurrence (see Figure 1). In that context, the effects of distractor's novelty or significance on performance were investigated.

Distraction Effects (Distractor Reaction Times [RTs] > Standard RTs)

In typical oddball paradigms, rarely presented deviant or novel stimuli (distractors) are embedded in a sequence of frequently presented repeated standard stimuli (standards). For investigating processes underlying distraction, participants typically perform a forced-choice discrimination task not related to the distractor sound or to the distracting features. For example, standard and distractor sounds have two different durations each. Participants are instructed to distinguish the sounds' duration. Whether the sound is a standard or distractor is not relevant for the duration discrimination task (both sounds can be long or short). Nevertheless, distractor sounds result in behavioral impairment usually interpreted as distraction (e.g., Schröger & Wolff, 1998). The brain's automatic detection of novelty or deviancy is reflected by the N1 and MMN components of the event-related potential (for a review, see Alho, 1995; Duncan et al., 2009; Garrido, Kilner, Stephan, & Friston, 2009; Kujala, Tervaniemi, & Schröger, 2007; Näätänen, 1992). N1/MMN can be followed by an attentional orienting toward these distractors, which is reflected by the P3a or novelty P3 component (for a review, see Escera, Alho, Schröger, & Winkler, 2000; Friedman, Cycowicz, & Gaeta, 2001; Polich & Criado, 2006). It is discussed that the costs of attentional orienting result in prolonged RTs or reduced hit rates (Berti, Roeber, & Schröger, 2004; Escera et al., 1998; Muller-Gass & Schröger, 2007; Rinne, Sarkka, Degerman, Schröger, & Alho, 2006; Schröger & Wolff, 1998;

* Address correspondence to Nicole Wetzel, Institute of Psychology, University of Leipzig, Neumarkt 9−19, D-04109 Leipzig. Email: wetzel@uni-leipzig.de

Wetzel et al., 2006). This distractor-related pattern at the electrophysiological and behavioral levels has been reported in unimodal auditory–auditory (Schröger & Wolff, 1998; Wetzel et al., 2006) and visual–visual (Berti & Schröger, 2001; Kimura, Katayama, & Murohashi, 2008) distraction paradigms, as well as in cross-modal distraction paradigms (Bendixen et al., 2010; Escera et al., 1998; Sussman, Winkler, & Schröger, 2003; Wetzel & Schröger, 2007a; Wetzel, Widmann, & Schröger, 2009). Qualitatively similar (albeit relative to controls sometimes attenuated or increased) distraction effects have been obtained in different populations such as children aged 6–12 years (Horvath, Czigler, Birkas, Winkler, & Gervai, 2009; Wetzel et al., 2006), 5-year-old children born preterm (Mikkola et al., 2010), elderly people (Mager et al., 2005), children suffering from attention deficit/hyperactivity disorder (ADHD; Gumenyuk et al., 2005), schizophrenic patients (Cortinas et al., 2008), patients suffering from alcoholism (Polo et al., 2003), and patients suffering from Chorea Huntington (Beste, Saft, Güntürkün, & Falkenstein, 2008). Moreover, the effects of various pharmaceutical substances (e.g., ethanol [Jääskeläinen, Schröger, & Näätänen, 1999], dopamine [Kähkönen et al., 2002], and nicotine [Knott et al., 2009]) on these effects have been studied.

Facilitation Effects (Distractor RTs < Standard RTs)

Distraction effects are usually explained by the costs of the switch of attention toward the distractor (Schröger & Wolff, 1998; Horvath, Roeber, Bendixen, & Schröger, 2008; Parmentier, Elford, Escera, Andres, & San Miguel, 2008). However, it should be noted that new or salient events elicit an orienting response (Sokolov, 1963) and may activate two separate processes, an attention switch and an increase in unspecific arousal (Näätänen, 1992). Increased arousal can facilitate sensory and motor functions, their central integration, and the available capacity (e.g., Kahneman, 1973).

There are recent studies that found no distraction effects or even facilitation effects in typical distraction paradigms. In an auditory–visual oddball study, SanMiguel et al. (2010) reported effects of attentional demands on performance. They suggested a relation between attentional task demands, arousal, and distraction or facilitation effects. Studies by Sussman et al. (2003), Wetzel and Schröger (2007a), Wetzel et al. (2009), and Horvath, Sussman, Winkler, and Schröger (2011) show that voluntary control can also prevent distraction; for example, when the occurrence of an deviant or novel sound is predicted by a visual cue. In that case, distraction effects caused by task-irrelevant sounds can be reduced or completely avoided (Horvath et al., 2011; Sussman et al., 2003; Wetzel & Schröger, 2007a; Wetzel et al., 2009). Furthermore, and most important for the present study, variation of the informational content of task-irrelevant deviant sounds regarding the onset time and probability of occurrence of a following target can abolish distraction effects or even result in facilitation effects (Parmentier et al., 2010). This is an interesting finding as, to our knowledge, in all auditory–visual oddball studies that report distraction effects, the sound–target intervals are constant and every sound is followed by a visual target (Parmentier et al., 2010). This design implies that sounds are informative regarding the certainty of appearance and the time of occurrence of a following target. However, the modulation of informational content affects performance dramatically, as reported by Parmentier et al. (2010). They occasionally presented white noise stimuli (deviants)[1] embedded in a sequence of frequently presented sine wave sounds (standards). When none of the sounds was informative regarding time and probability of target occurrence, RTs in standard and deviant trials were identical; that is, no distraction effects were observed. Parmentier et al. concluded that the auditory deviancy per se is not sufficient to yield behavioral distraction. This means that distraction effects are only elicited in auditory–visual oddball paradigms when the informational content of standard and distractor sounds regarding time and occurrence of a target is used by the cognitive system.

The Role of Novelty and Significance of Distractor Sounds

Distraction effects were elicited by sounds that differ from standard sounds in one dimension (e.g., frequency; Schröger & Wolff, 1998) or in many dimensions such as noise (e.g., Parmentier et al., 2010) or environmental novels (e.g., Escera et al., 1998; Wetzel et al., 2009). There are only a few studies that directly compare slightly changed deviant sounds with novel sounds (relative to standard sounds) and their effects on performance or attentional orienting (Alho et al., 1998; Escera et al., 1998; Escera, Yago, & Alho, 2001; Polo et al., 2003; Wetzel & Schröger, 2007b). In an auditory–visual oddball study, Escera et al. (1998) reported prolonged RTs in trials including natural novel sounds compared with standard sounds, whereas in trials including pitch-changed sounds, reduced hit rates were observed relative to standard sounds. Differences in change detection and attentional orienting, reflected by N1/MMN and P3a (biphasic in novel trials), were also observed. Escera et al. concluded that unexpected slight changes and natural novel sounds trigger two separate mechanisms of involuntary attention and result in different types of behavioral distraction. Also, Polo et al. (2003), who studied patients suffering from alcoholism

[1] Parmentier et al. (2010) termed the distractor *novel*, but in the nomenclature of the present article it is termed *deviant*. In the present article, novels are defined as environmental sounds that are presented only once during the stimulation.

compared with healthy controls, observed a similar event-related potential (ERP) pattern elicited by pitch changes and natural novel sounds in an auditory–visual oddball paradigm. However, their results on the behavioral level differ from the results reported by Escera et al. (1998): Both deviant and novel sounds prolonged RTs in the visual task but processing of novel sounds resulted in larger prolongation of RTs than processing of pitch-changed sounds (compared with corresponding standard trials). In contrast to Escera et al. (1998), no effects in terms of decreased hit rate were observed. In another auditory–visual oddball study, Escera et al. (2001) also reported prolonged RTs for pitch deviant and environmental novel sounds. The hit rate was only reduced in deviant trials. In general, pitch deviant and novel sounds differ from each other in the amount of physical deviation from regular standards, in repetition (deviant sounds are always repeated), and in meaning (natural novel sounds include, e.g., dog barking or clank of glasses). All three features are suggested to affect attentional orienting. Increased amount of physical degree of deviation can increase attentional orienting (Berti et al., 2004; Wetzel et al., 2006; Yago, Corral, & Escera, 2001). The repeated presentation of distracting sounds can decrease attentional orienting (Cycowicz & Friedman, 1998; Cycowicz, Friedman, & Rothstein, 1996). Personal significance or meaning of distractor sounds are suggested to increase attentional orienting (e.g., Escera, Yago, Corral, Corbera, & Nuñez, 2003; Holeckova, Fischer, Giard, Delpuech, & Morlet, 2006; Roye, Jacobsen, & Schröger, 2007). Other authors did not report such modulation of attentional orienting or even reduced attentional orienting by interesting sounds in adults (Mecklinger, Opitz, & Friederici, 1997; Opitz, Mecklinger, Friederici, & von Cramon, 1999; Wetzel, Widmann, & Schröger, 2011).

Furthermore, environmental novels are motivationally significant stimuli. Brain responses and performance to such stimuli can be facilitated by the locus coeruleus–norepinephrine (LC-NE) system (Aston-Jones & Cohen, 2005; Nieuwenhuis, De Geus, & Aston-Jones, 2010). The LC-NE system can explain effects on behavior that were conventionally described in terms of arousal (Aston-Jones & Cohen, 2005).

Results of the cited studies assume that physical deviation from standards, repeated presentation, and significance of task-irrelevant distractor sounds can affect attentional orienting or performance. For that reason, we varied not only the informational content of task-irrelevant sounds regarding time and probability of target occurrence but also the nature of distractor sounds by comparing a burst of white noise (replicating Parmentier et al., 2010) with environmental, unrepeated novel sounds.

Aims and Hypotheses of the Present Study

Meaningless sounds are not interesting for the listener (James, 1890). As described in the previous paragraph, deviant and significant novel sounds may differently affect attentional orienting and performance. It cannot be excluded that the surprising finding of an improvement of performance reported by Parmentier et al. (2010) is confined to artificial deviant sounds (bursts of white noise). Meaningful novel sounds, which are interesting for the listener, will possibly keep their distracting potential. In the present study, we aimed to test whether environmental novel sounds are only distracting when the cognitive system can take advantage of their processing to optimize performance, as postulated by Parmentier et al. (2010). In addition, the present study examines the potential effect of informational content on the performance not only of the distractor but also of the frequently presented standard sounds. This is relevant, as distraction effects are determined as the difference in performance between trials with a distractor and trials with a standard sound. We discuss our hypotheses for the four conditions described here (see Table 1). In the informative condition, all sounds predicted target onset time by a constant sound–target interval and target occurrence with a probability of 100%. As in many studies including novel or deviant sounds, distraction effects were expected (Escera et al., 1998; Parmentier et al., 2010; Wetzel et al., 2009). In the uninformative condition, neither standard nor distractor sounds carried this information by using variable sound–target intervals and a target probability of 50%. We expected similar behavioral effects for the deviant version, as reported by Parmentier and colleagues (2010), who obtained no differences in RTs and hit rates between standard and deviant trials. For the novel version, we hypothesized two opposite scenarios: On the one hand, uninformative novel sounds could elicit increased distraction effects (Escera et al., 2001; Polo et al., 2003). This could be due to the novelty and semantic content of novel sounds. On the other hand, the arousal component of the orienting response elicited by novel sounds could improve performance (Näätänen, 1992). Furthermore, environmental novel sounds are motivationally significant stimuli. Brain responses and performance to such stimuli can be facilitated (Aston-Jones & Cohen, 2005; Nieuwenhuis et al., 2010). For that reason, performance could be improved in novel trials compared with deviant trials.

Responses to targets that are predictable in time and probability of occurrence by task-irrelevant sounds (informative condition) were expected to be faster than responses to unpredictable targets (uninformative condition; see Parmentier et al., 2010). This hypothesis is in line with findings from cueing paradigms (e.g., Näätänen, Alho, & Schröger, 2002). Results of Parmentier et al. (2010), in a condition in which deviants were informative but standards were not, indicate that benefits of this cueing effect are larger than the costs of attentional orienting toward the deviant (Parmentier et al., 2010). In turn, in an additional condition in the present article, where standards but not distractors were informative, the benefit of cuing and the costs of attentional orienting added up and large distraction effects were expected. In accordance with the study by Parmentier and colleagues (2010), we expected facilitation effects in the distractor informative condition (distractors are informative but standards are not). For the standard informative condition (standards are informative but distractors are not), we expected the informational content of standards to play a role similar to that of the informational content of distractors. Therefore, we expected faster RTs in informative standard trials compared with noninformative distractor trials, resulting in strong distraction effects in the standard informative condition (see Table 1).

Method

Participants

Forty-eight healthy adults were assigned to four conditions in a between-participants design. Each condition was performed by 12 participants. Handedness was measured with a shortened German version of the Edinburgh Handedness Inventory (Oldfield, 1971). Participants' mean ages were 25 years, 0 months in the informative condition (6 female, 9 right handed); 24 years, 4 months in the uninformative condition (9 female, 8 right handed); 24 years, 9 months in the distractor informative condition (8 female, 7 right handed); and 24 years, 11 months in the standard informative condition (5 female, 9 right handed). Participation was rewarded by money. All participants gave written informed consent and reported having normal hearing, normal or corrected-to-normal vision, and no history of suffering from attention-related disorders.

Stimuli

The informational content of sounds regarding time and occurrence of a visual target was varied between participants in four conditions by modulating the interval between sound and target and by the probability of target occurrence (see Figure 1). The study was performed in an acoustically attenuated cabin. Participants were seated in front of a 1.15-m screen. Sounds were presented through headphones (Sennheisser HD 25–1).

Sounds. The novel version of the auditory–visual distraction paradigm, with novel sounds as distractors, comprises 120 environmental novel sounds[2] selected from a commercial CD (1,111 Geräusche, Döbeler Cooperations, Hamburg, Germany). The standard sound on this version was a part of the gong of a bell. In the deviant version of the auditory–visual distraction paradigm, a burst of white noise served as the deviant sound and a sine wave sound of 600 Hz served as the standard sound. All sounds had a duration of 200 ms, including 10 ms faded ends. Sounds were RMS matched and presented with a 68 dB sound pressure level (measured with an HMS III artificial head; HEAD Acoustics, Herzogenrath, Germany).

Pictures. Target pictures were white line drawings of 10 animals and 10 pieces of clothing presented on a black background. Pictures were selected from Alario and Ferrand's (1999) database and were presented with a 4.33° × 4.33° viewing angle. The white fixation cross had an extension of 0.55° × 0.55°.

Instruction. The procedure of the study was explained first. All pictures were displayed, and it was determined whether the participants could identify each picture. For the experimental part, participants were instructed to distinguish animals and clothes as fast and as correctly as possible by pressing the button assigned to the respective category with the left or right thumb. Participants were instructed to ignore all sounds and were informed about the possibility that sometimes no picture appears and no response is required. Participants were not informed about the relation between sounds and targets.

Procedure

The experiment was preceded by a short training including 10 pictures but no sounds. Each of the four conditions (see Table 1) included the deviant and the novel versions of the paradigm. The order of the versions was balanced across participants. Each version included 120 distractor trials and 480 standard trials, divided into six blocks. The trial structure is displayed in Figure 1. The constant sound–target interval was 100 ms; stimulus onset asynchrony (SOA) was 300 ms. The time between the onset of two sounds was 1.450 ms. In conditions with a variable sound–target interval, the intervals were 0, 50, 100, 150, and 200 ms (SOA = 200, 250, 300, 350, and 400 ms, respectively) occurring with equal probability. Distractor trials were presented with a probability of 20%. Standard and distractor trials were presented pseudorandomly, with the restriction that at least two standard trials preceded a distractor trial. Each

[2] The deviant sound and examples of novel sounds can be found online at http://www.uni-leipzig.de/~biocog/wetzel/faz1_deviant.wav; http://www.uni-leipzig.de/~biocog/wetzel/faz1_novel1.wav; and http://www.uni-leipzig.de/~biocog/wetzel/faz1_novel2.wav

novel sound was presented only once during the session. Both target categories were presented equiprobably per condition and version. Furthermore, targets following distractors and standards were equiprobably assigned to animals or clothes. The fixation cross was presented constantly except during target presentation. The mapping of buttons to the target category was balanced across participants. The experimental session, including breaks, lasted for about 1 hr.

Statistical Analyses

RTs and hit rates were measured. We tested the effects of the sounds' informational content on RTs and hit rates using repeated-measures analyses of variance (ANOVAs), with version (novel, deviant) and sound type (standard, distractor) as the within-participant factors and condition (informative, uninformative, distractor informative, standard informative) as the between-participants factor. Trials including the first sound after a distractor were excluded. An alpha of .05 was defined for all statistical tests.

Results

RTs

RTs are displayed in Figure 2 and Table 2. An ANOVA of version, sound type, and condition revealed no statistically significant interaction, $F(3, 44) = 0.79$, $p < .51$; $\eta_p^2 = .05$. The statistically significant interaction of Sound Type × Condition, $F(3, 44) = 71.96$, $p < .001$, $\eta_p^2 = .83$, indicates that distraction effects were affected by the informational content of the sounds. The statistically significant follow-up *t* tests show that the availability of information determines whether distraction or facilitation effects were observed. The *t* values for standard RT versus distractor RT for each condition are as follows: informative condition, $t(11) = −5.97$, $p < .001$; uninformative condition, $t(11) = 2.99$, $p < .012$; distractor informative condition, $t(11) = 5.75$, $p < .001$; and standard informative condition, $t(11) = −9.65$, $p < .001$.

The statistically significant interaction of Version × Sound Type, $F(1, 44) = 8.61$, $p < .005$, $\eta_p^2 = .16$; indicates that distraction effects differ between the novel version and the deviant version. The respective follow-up *t* tests comparing standards and distractors for each version are not statistically significant because distraction and facilitation effects cancelled each other out across the four conditions. As can be seen in Figure 3 and Table 2, this interaction can be resolved as follows: Novel sounds in the novel version result either in decreased distraction or in increased facilitation effects relative to deviant sounds in the deviant version of the paradigm. The condition unspecificity of the bias toward facilitation for novel sounds compared with standard sounds was confirmed by an additional ANOVA testing the difference of distraction effects between versions ([novel RT – standard RT] – [deviant RT – standard RT]) across conditions and was shown to be not significant, $F(1, 3) = 0.789$, $p < .507$; $\eta_p^2 = .051$.

There was no statistical interaction between version and condition, $F(3, 44) = 0.20$, $p < .89$; $\eta_p^2 = .01$.

Furthermore, main effects of sound type, $F(1, 44) = 16.93$, $p < .001$, $\eta_p^2 = .28$; and condition, $F(3, 44) = 3.49$, $p < .023$, $\eta_p^2 = .19$; were statistically significant. Effects of sound type existed either in distraction (prolonged RTs in distractor relative to standard trials) or in facilitation (shortened RTs in distractor relative to standard trials), depending on the condition or version of the paradigm. In general, RTs were fastest when both distractors and standards were informative. There was no main effect of version, $F(1, 44) = 0.5$, $p < .49$; $\eta_p^2 = .011$.

Hit Rates

Participants achieved a high performance level (96% hit rate). The ANOVA with the factors version, sound type, and condition was statistically significant, $F(3, 44) = 2.86$, $p < .048$, $\eta_p^2 = .16$. In follow-up tests for each condition, the Version × Sound Type interaction was significant only for the standard informative condition, $F(1, 11) = 8.03$, $p < .016$, $\eta_p^2 = .42$. The follow-up *t* test for the standard informative condition compared the hit rate in novel and deviant trials with those of the respective standard trials: for the novel version, $t(11) = 2.11$, $p < .06$; for the deviant version, $t(11) = 5.41$, $p < .001$ (see Table 3).

Further subordinate effects were statistically significant: For main effect of sound type, $F(1, 44) = 11.78$, $p < .001$, $\eta_p^2 = .21$; for main effect of Sound Type × Condition, $F(3, 44) = 8.13$, $p < .001$, $\eta_p^2 = .36$. There was no effect of version, $F(1, 44) = 0.28$, $p < .60$, $\eta_p^2 = .006$; Version × Condition, $F(3, 44) = 1.10$, $p < .36$, $\eta_p^2 = .07$; or Version × Sound Type, $F(1, 44) = 1.95$, $p < .17$, $\eta_p^2 = .04$.

Post Hoc Analyses

For explaining the asymmetry between the benefit of information for standards (54 ms; standard informative condition, mean novel and deviant versions) and for distractors (26 ms; distractor informative condition, mean novel and deviant versions; see Table 2 and Figure 2), we conducted a post hoc ANOVA with the factors distraction effects of version (novel RT – standard RT, deviant RT – standard RT) and condition (distractor informative condition, standard informative condition). The interaction was statistically not significant, but the main effect of condition reached significance, $F(1, 22) = 123.35$, $p < .001$, $\eta_p^2 = 0.85$.

Discussion

In an auditory–visual distraction paradigm, we applied four conditions varying the informational content of task-irrelevant novel and deviant sounds with respect to the onset time and probability of occurrence of a visual target. The analyses of RTs reveal (1) a statistically significant interaction of version and sound type, indicating different distraction or facilitation effects in the novel version compared with the deviant version. (2) Furthermore, a statistically significant interaction of sound type and condition indicates modulations of distraction effects by the sounds' informational content.

An Unspecific Facilitation Effect Elicited by Novels

Statistical results show that the distraction effects differ between the novel version and deviant version (see Figure 3). Overall, RT effects in the novel version are characterized by decreased distraction or increased facilitation effects relative to the respective deviant version across conditions. For example, in the uninformative condition, environmental novel sounds cause a facilitation effect, whereas, replicating Parmentier et al. (2010), a burst of white noise did not (see Figure 2). In other words, we obtained a novel-related bias toward facilitation independent from informational content; that is, the bias toward facilitation in novel trials is of an unspecific nature. The novel-related facilitation effect could be explained in the context of arousal. New and unexpected events can elicit the orienting response (Näätänen, 1992; Sokolov, 1963). Whereas the attentional component of the orienting response is usually emphasized to explain distraction, the arousal component has often been neglected. The unspecific bias toward facilitation caused by novel sounds in the present study could be explained by the influence of the arousal component on performance. It can be assumed that novel sounds as motivationally significant stimuli temporarily enhance the arousal (the increase of activity in terms of the LC-NE theory) to a more optimal level that improves performance (Aston-Jones & Cohen, 2005; Nieuwenhuis et al., 2010; SanMiguel et al., 2010; van Mourik, Oosterlaan, Heslenfeld, Konig, & Sergeant, 2007).

A novel-related increase of arousal in the context of improved performance is also discussed in research with children suffering from attention deficit/hyperactivity disorder (ADHD). It is suggested that such children have an energetical dysfunction (for review see, Sergeant, 2005). Novel events increase arousal, which results in enhanced performance in novel trials in ADHD children (e.g., van Mourik et al., 2007). In the present study, deviant sounds are suggested to be less activating than novel sounds because they are less motivationally significant. Therefore, the benefit from arousal enhancement is probably smaller in deviant trials than in novel trials. This results in stronger distraction or reduced facilitation effects in the deviant version (see Figure 3). The bias toward speeded RTs in novel trials compared with deviant trials is not in line with results by Polo et al. (2003) and by Escera et al. (2001), who reported (marginally) prolonged RTs in novel trials compared with deviant trials. This can be due to differences in the experimental protocol. For example, novel sounds and deviant sounds were presented in different blocks in the present study, whereas the presentation was mixed in the studies of Polo et al. (2003) and Escera et al. (2001). Moreover, repetition effects of novel sounds can be excluded in the present study but not in the referred studies, where each novel was presented 2–3 times during the session. Furthermore, the processing of white-noise deviants in the present study activates a broader network than simple-pitch deviants and is, regarding its physical features, more similar to the processing of environmental novel sounds than that of pitch deviants. This means white-noise deviants have a larger distraction potential than pitch deviants but are meaningless and, consequently, less motivationally significant stimuli. The present results show that the nature of the distractor sounds strongly modulates performance and should be considered in further investigation of novel processing. The present results support the assumption that the processing of deviants and novels is qualitatively and quantitatively different (Alho et al., 1998; Escera et al., 1998; Wetzel & Schröger, 2007b).

The Use of Information Provided by Standard and Distractor Sounds

When standard and distractor sounds carry information with respect to the onset time and probability of target occurrence − as in the informative condition − typical distraction effects (distractor RT − standard RT) are observed for the novel and the deviant versions (see Figure 2 and Table 2). This result is in line with results obtained in typical auditory–visual oddball studies (e.g., Escera et al., 2001; Polo et al., 2003). It can be explained within the classical involuntary attention account according to which deviant or novel sounds elicit a call for attention. As a consequence, less resources are available for performing the primary task, resulting in impaired performance (e.g., Escera et al., 2000; Näätänen, 1992). It is interesting, however, that the pattern of RTs in the uninformative condition reveals that neither novels nor deviants cause prolonged RTs relative to standards. On the contrary, novels cause facilitation effects; that is, RTs in novel trials are faster than in standard trials. This result contradicts attentional theories, because distractor sounds should call for attention regardless of whether they are or are not informative with respect to the time and occurrence of the target. The absence of distraction effects in the uninformative condition could be explained in two ways. (1) It could be that the processing intensity of task-irrelevant sounds depends on their informational content. In the informative condition, the task-irrelevant information provided by sounds is used by the cognitive system to increase performance. This information is not directly relevant for the ongoing task but can be relevant for a general response preparation. The use of the information could require a more intensive processing of informative sounds relative to uninformative sounds. One consequence could be that the cognitive system cannot shield target-related processing from effects of distractor processing in the informative condition. Nevertheless, the cognitive system benefits from processing the information as can be seen by faster RTs in the informative condition compared with the uninformative condition (see Figure 2). In contrast, in the uninformative condition, sounds are not informative and less intensive processing is sufficient. Consequently, the cognitive system can shield target-related processing much more efficiently from effects of distractor-related processing, resulting in absent distraction effects but also in prolonged mean RTs (see Figure 2). (2) Alternatively, it could be that sounds in the uninformative condition are basically processed in the same way as in the informative condition. In that case, distractor sounds cause similar costs of attentional orienting. This is in line with the hypothesis by SanMiguel et al. (2010). They postulated that novels always cause orienting costs and arousal benefits. Whether distraction or facilitation results depend on the baseline level of attentional focusing induced by the primary task. Whenever the costs of orienting are larger than the benefits of arousal, novels cause distraction effects. Whenever orienting costs are smaller than arousal benefits, novels result in facilitation. Tasks with high attentional demands are performed on an optimal level of arousal, and novel-related benefits of arousal increase have no further consequences on performance. In contrast, in an easy task attentional resources are not optimally used and "unfocused attention costs" occur which can be (over)compensated by novel-related arousal benefits (SanMiguel et al., 2010). According to the present informative and uninformative conditions, the required attentional demands and resources are suggested to be different. In the informative condition, information provided by the sounds is processed and responses are speeded. The cognitive system presumably operates on a rather optimal level, which is not the case in the uninformative condition. Thus, in the uninformative condition, the benefit from arousal increase elicited by distractor sounds could be large enough to compensate costs of attentional orienting. This explanation would be in line with the classical involuntary attention account.

In summary, results show that our cognitive system selectively uses information from standard and distractor sounds about the onset time and occurrence of a target. Please note that this information is not directly task related, as it does not inform about which target will appear. It only informs about the fact that a target will occur and when in time the target will occur.

A Model Integrating Costs of Attentional Orienting and Benefits of Information and Activation

As discussed in the previous paragraphs, we observed improved performance when task-irrelevant sounds were informative. Furthermore, we observed improved performance in the context of novel sounds relative to deviant sounds independent from information. Finally, the significant asymmetry between the benefit by information for standards (54 ms; benefit for standards in the standard informative condition relative to distractors, mean novel and deviant versions) and for distractors (26 ms; benefit for distractors in the distractor informative condition relative to standards, mean novel and deviant versions) is to be discussed (see Figure 3 and Table 2). RTs are speeded up by information on time and probability of target occurrence as demonstrated by the RT difference between informative and uninformative conditions, obviously, as they can be used as warning signals if they appear reliably. Distractor sounds occur less frequently in the distractor informative condition than standards in the standard informative condition. The observed asymmetry in benefit by information could be explained by weaker stimulus–response associations making the extraction of onset and probability information more difficult (Hommel, Müsseler, Aschersleben, & Prinz, 2001). However, this explanation leads to the question of why distractor sounds in the distractor informative condition are still processed markedly more slowly than in the informative condition (where standards *and* distractors are informative). Furthermore, it cannot be explained why this effect is of comparable size for deviants and novels (with novels, because of their uniqueness, having even weaker stimulus–response associations) or why distractor sounds should not cause distraction in the distractor informative condition.

However, the asymmetry between the information benefit between standards and distractors, as well as the observed data pattern as a whole, can be explained with a lower number of assumptions and in a more straightforward manner as follows: The observed effects are interpreted as the sum of a facilitation effect by a reliable warning signal (informative sounds) and a distraction effect caused by deviant and novel sounds. In the distractor informative condition, the sum of distractor RTs comprises a facilitation effect through a reliable warning signal given by informative distractors (benefits) and a distraction effect elicited by distractor sounds (costs). In the standard informative condition, distractor sounds are uninformative and cannot act as warning signals but cause distraction effects. Thus, distractor RTs include costs of distraction but no information-related facilitation and are increased in the standard informative condition, compared with the distractor informative condition. Additionally, information-related facilitation effects are caused by informative standard sounds in the standard informative condition. Consequently, the RT differences between standard and distractor sounds are larger in the standard informative condition than in the distractor informative condition. Almost all effects of the present data pattern could consequently be explained by only three assumptions: (1) Novel sounds elicit unspecific activation, speeding RTs. (2) Information in sounds on onset and occurrence of targets act as warning signals, speeding RTs. (3) Rare sounds (deviants and novels) elicit distraction when *any* sound is informative; that is, sounds cannot be ignored as in the uninformative condition.

In fact, the present pattern of results can be predicted by a linear model with the following parameters: an unspecific novel-related activation effect of –8 ms, a warning signal facilitation effect of −38 ms, and a distraction effect of 16 ms, as estimated from the relevant parts of the observed results. The unspecific novel-related activation effect of −8 ms was estimated from the mean difference of distraction/facilitation effects in the novel and the deviant versions in all four conditions (see Figure 3 and Table 2). The warning signal facilitation effect of −38 ms was estimated from the difference of the mean RTs in informative and uninformative trials (in the informative trial: standards and distractors of the informative condition, distractors of the distractor informative condition, and standards of the standard informative condition; in the uninformative trial: standards and distractors of the uninformative condition, standards of the distractor informative condition, distractors of the standard informative condition). The distraction effect of 16 ms was estimated as distractor minus standard RT in the informative condition. With the model computed with a base RT of 452 ms (estimated from the mean RT for all uninformative standards, i.e., the standards from the uninformative and the distractor informative conditions) and the unspecific novel-related activation effect, the warning signal facilitation effect and the distraction effect result in the modeled data shown in Figure 4. The predictions of this a posteriori model match the actual pattern of results. The asymmetry between facilitation effects for distractor sounds in the distractor informative condition (observed 26 ms mean of novel and deviant versions) and standards in the standard informative condition (observed 54 ms mean of novel and deviant versions) is predicted almost precisely (26 ms and 50 ms, respectively; see Figure 4). Thus, our alternative explanation is plausible and parsimonious, even if it cannot yet be finally proven on the basis of the presented data. An ERP study investigating P3a, which is associated with attentional orienting and distraction, could support our assumptions.

In summary, are distraction and facilitation actually two faces of the same coin? No, as the results of the present study suggest an unspecific bias toward facilitation caused by environmental novel sounds compared with artificial deviant sounds. Distraction or facilitation effects are further determined by the informational content of standard and distractor sounds with respect to the onset time and the probability of target occurrence. It is suggested that the observed effects result from a superposition of distraction effects caused by novels and deviants when the sounds are at least partly informative and facilitation effects caused by warning signals informative with respect to onset and probability of target occurrence.

Conclusions

(1) Novel sounds, in contrast to deviant sounds, cause a bias toward facilitation independent of the sounds' informational content regarding time and probability of target occurrence. This result suggests fundamental differences in the underlying mechanisms during processing of ecological valid novel sounds and repeated artificial deviant sounds. (2) Task-irrelevant novel sounds or deviant sounds do not necessarily result in behavioral distraction effects. (3) The informational content of sounds has a strong effect on facilitation or distraction effects, indicating the use of task-irrelevant but target-related information by the cognitive system for enhancing performance. (4) There are strong indications that performance in distractor trials is the sum of the costs of attentional orienting, the benefits of information, and the benefits of unspecific activation (novel sounds).

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Table 1.
The Four Conditions in Which the Information Content of Sounds Regarding Time and Probability of Target Appearance Was Varied

Condition	Standard sounds	Novel/deviant sounds	Hypothesized outcome
Informative	+	+	Distraction effects
Uninformative	–	–	Distraction or facilitation effects in the novel version No effects in the deviant version
Distractor informative	–	+	Facilitation effects
Standard informative	+	–	Strong distraction effects

Note. For each condition, both the novel version (including environmental novel sounds that were not repeated) and the deviant version (including a burst of white noise) were performed. A plus sign indicates "informative" (constant sound–target interval and 100% probability of target appearance). A minus sign indicates "not informative" (variable sound–target interval and 50% probability of target appearance).

Table 2.
Reaction Times (in Milliseconds) in the Four Conditions

Condition	Novel version				Deviant version			
	Standard	Novel	Difference (novel − standard)	p	Standard	Deviant	Difference (deviant − standard)	p
Informative	400	413	**13**	**< .006**	398	414	**16**	**< .001**
Uninformative	447	432	**-15**	**< .002**	446	444	-2	< .560
Distractor informative	458	428	**-30**	**< .001**	455	432	**-23**	**< .001**
Standard informative	390	440	**50**	**< .001**	390	448	**58**	**< .001**

Note. Bold type means that distractor and standard RT differ statistically significant from each other (t-test comparison).

Table 3.
Hit Rates (%) in the Four Conditions

Condition	Novel version				Deviant version			
	Standard	Novel	Difference (novel − standard)	*p*	Standard	Deviant	Difference (deviant − standard)	*p*
Informative	95.4	95.9	-0.5	< .45	95.4	96.4	-1.0	< .14
Uninformative	96.5	97.0	-0.5	< .59	96.8	96.1	-0.7	< .19
Distractor informative	96.9	96.6	-0.3	< .64	96.2	96.5	-0.3	< .65
Standard informative	92.3	95.0	2.7	< .06	92.2	97.4	**5.2**	**< .001**

Note. Bold type means that distractor and standard RT differ statistically significant from each other (t-test comparison).

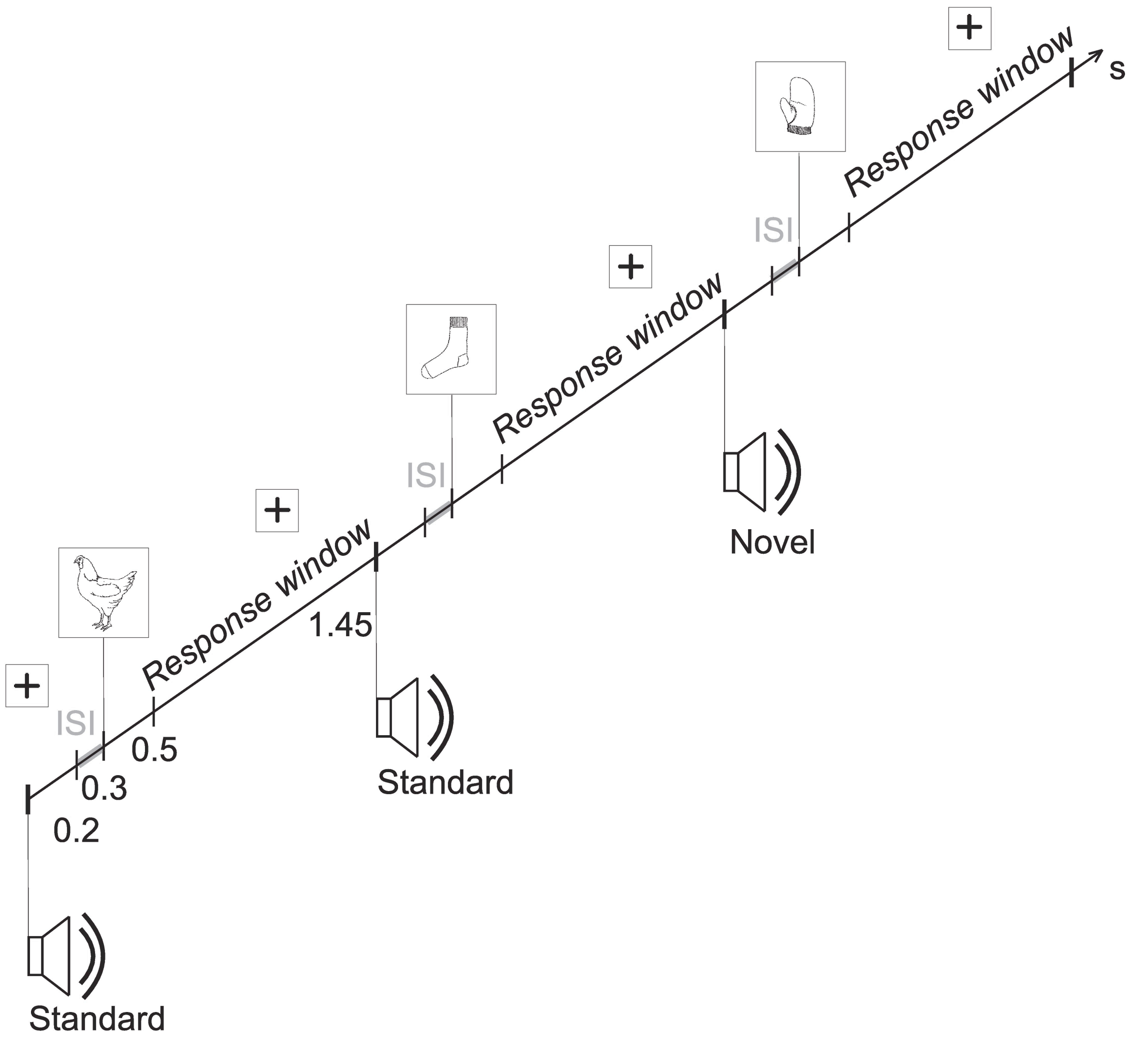

Figure 1.
Trial. Task-irrelevant sounds were followed by visual targets, which have to be classified as belonging to either the animal category or the clothes category. When the interstimulus interval (ISI) between sound and target is constant (100 ms) and every sound is followed by a target (100% probability), then the sounds are informative regarding onset time and probability of occurrence of targets. When the ISI is variable (0 ms, 50 ms, 100 ms, 150 ms, 200 ms) and only 50% of sounds are followed by a target (otherwise, a fixation cross is presented), then the sounds are not informative regarding onset time and appearance of targets. Note that the sounds never predict task-relevant features. The fixation cross is always presented except when a target is presented. To exemplify, in Figure 1, three trials of the novel version in the informative condition are displayed.

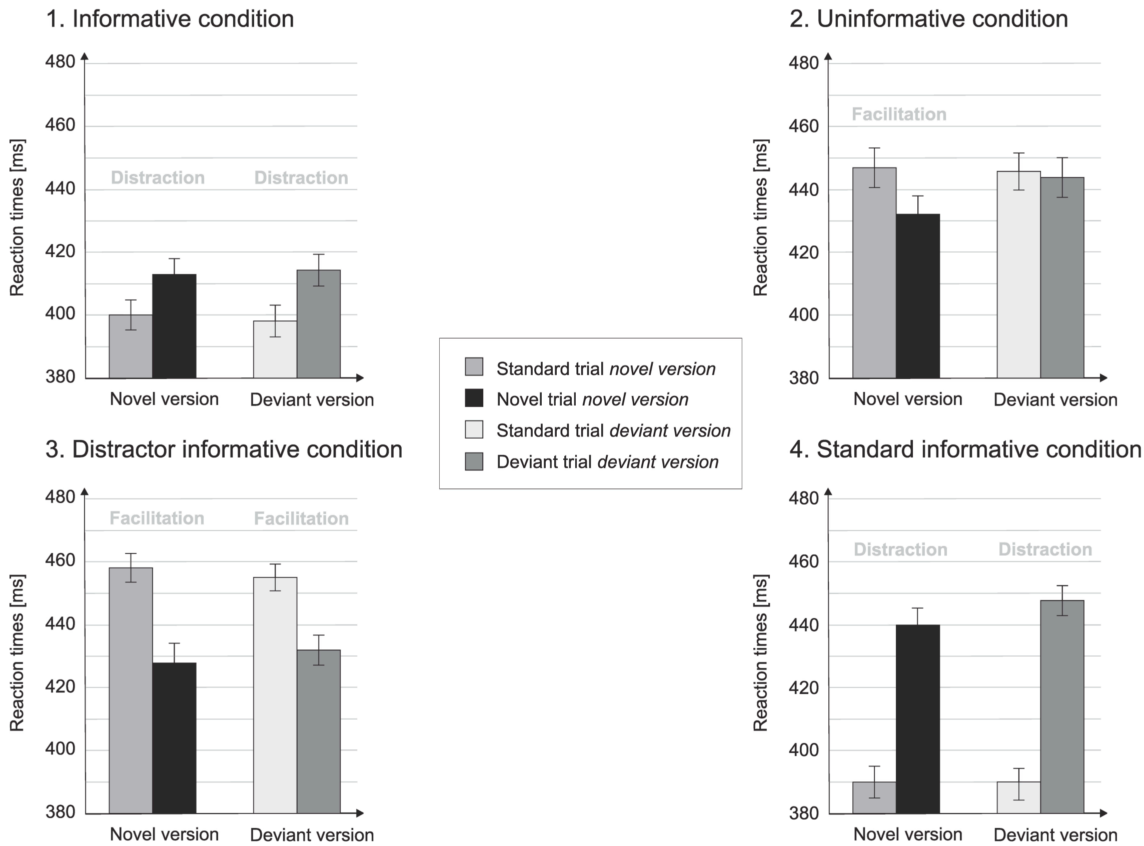

Figure 2.

Results. Reaction times (RTs) and standard errors of mean for the novel and deviant versions for each condition. In the informative condition, typical distraction effects were observed; that is, RTs in distractor trials were prolonged compared with those in standard trials. In the uninformative condition, RTs were faster in novel trials than in standard trials. This facilitation effect was not observed in the deviant version. In the distractor informative condition, RTs of informative novels and deviants were faster than those of uninformative standards. In contrast, in the standard informative condition, RTs of informative standards were faster compared with uninformative distractors.

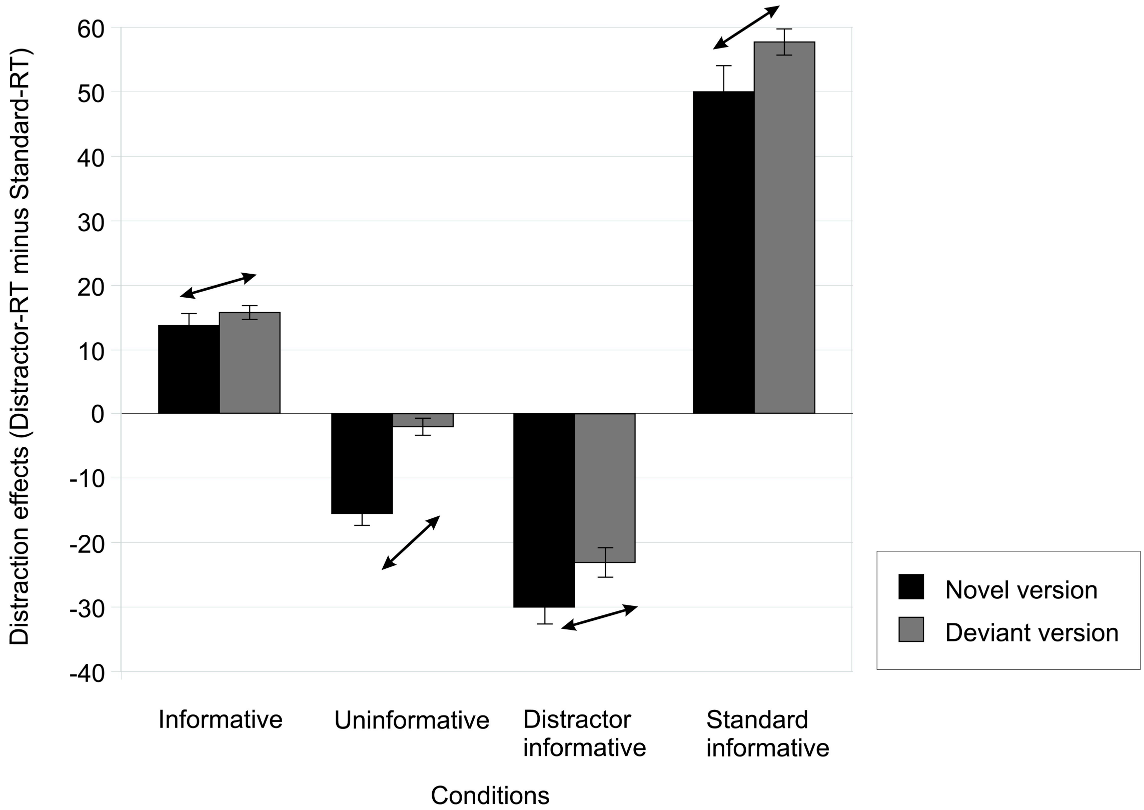

Figure 3.
Unspecific facilitation effect. In the novel version, relative to the deviant version, distraction effects show a bias to increased facilitation effects (lower bars) or respectively reduced distraction effects (upper bars). The bias to facilitation is marked by arrows.

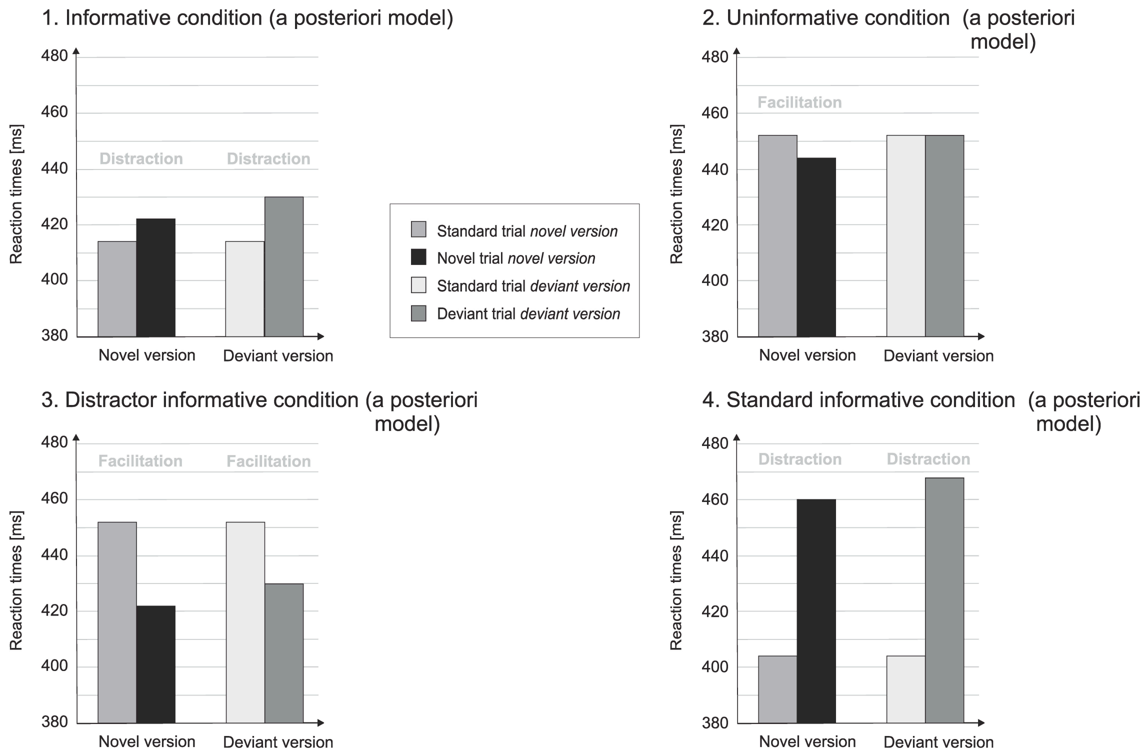

Figure 4.
Reaction time (RT) pattern predicted by an a posteriori model. Illustration of an RT pattern predicted by a linear model that integrates the costs of attentional orienting and benefits of information and novel-related activation with the following parameters: the costs of attentional orienting of 16 ms, a warning signal facilitation effect of −38 ms, and an unspecific novel-related activation effect of −8 ms. The pattern of RTs predicted on the basis of this a posteriori model is very similar to the pattern of results (see Figure 2).