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Why are auditory novels distracting? Contrasting the roles of novelty, violation of expectation and stimulus change

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ABSTRACT

Past studies show that novel auditory stimuli, presented in the context of an otherwise repeated sound, capture participants' attention away from a focal task, resulting in measurable behavioral distraction. Novel sounds are traditionally defined as rare and unexpected but past studies have not sought to disentangle these concepts directly. Using a cross-modal oddball task, we contrasted these aspects orthogonally by manipulating the base rate and conditional probabilities of sound events. We report for the first time that behavioral distraction does not result from a sound's novelty *per se* but from the violation of the cognitive system's expectation based on the learning of conditional probabilities and, to some extent, the occurrence of a perceptual change from one sound to another.

1. Introduction

A cornucopia of studies demonstrates that unexpected perceptual changes in our surroundings yield rapid, specific, and automatic brain responses. Much progress has been achieved in this field since the discovery of the mismatch negativity (MMN) response (Näätänen, Gaillard, & Mäntysalo, 1978) observed in passive auditory oddball tasks, 100–250 ms after the onset of a sound differing from an otherwise repetitive auditory context (e.g., Grimm, Widmann, & Schröger, 2004; Jacobsen, Horenkamp, & Schröger, 2003; Paavilainen et al., 2003). This response is widely interpreted as "the outcome of a comparison process that registers a difference between the neural representation of the actual input and the memory trace of the invariances inherent to the recent stimulation" (Schröger, 2005, p. 490) and is followed by involuntary orientation (P3a; e.g., Escera, Alho, Winkler, & Näätänen, 1998; Schröger, Giard, & Wolff, 2000) and re-orientation (RON; e.g., Berti & Schröger, 2001) brain responses.

Researched comparatively less, but at the core of our study, novel sounds also yield measurable *behavioral* effects. When participants are engaged in a focal task, novel sounds delay responses to contiguous target stimuli and, occasionally, reduce response accuracy (e.g., Dawson, Filion, & Schell, 1989; Grillon, Courchesne, Ameli, Geyer, & Braff, 1990; Schröger, 1997; Woodward, Brown, Marsh, & Dawson, 1991). This effect is observed in auditory (e.g., Berti & Schröger, 2003; Roeber, Berti, & Schröger, 2003; Schröger & Wolff, 1998), visual (Berti & Schröger, 2004), tactile (Parmentier, Ljungberg, Elsley, & Lindkvist, in press), and cross-modal oddball tasks (e.g., Andrés, Parmentier, & Escera, 2006; Parmentier & Andrés, 2010; Parmentier, Maybery, & Elsley, 2010).

In the cross-modal oddball task, participants categorize visual stimuli presented in sequence while ignoring sounds presented immediately before each target stimulus. On most trials, the same sound is presented (standard). On rare and unpredictable trials, the standard is replaced by

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a different sound (novel). Evidence indicates that behavioral distraction reflects a time penalty associated with the shift of attention to and from the novel sound rather than the slower processing of the visual targets *per se* (Parmentier, Elford, Escera, Andrés, & San Miguel, 2008). In addition, Parmentier (2008) showed that attention capture is followed by an involuntary semantic analysis of the novel's content which, when in conflict with a target stimulus (interfering with its processing), is followed by the inhibition of the distracter (Parmentier, Turner, & Elsley, 2011).

Recently, Parmentier, Elsley, and Ljungberg (2010) questioned the common assumption that novel sounds capture attention by virtue of their novelty *per se*. These authors suggested that behavioral novelty distraction might only occur when the cognitive system makes use of the sound as a valid warning cue, that is, when novelty occurs within a stream of information used by the brain for goal-relevant purposes. In line with this proposition, the authors demonstrated that when sound is stripped of its informational value (that is, when it did not announce a target or its temporal onset), novel sounds yielded no distraction. Furthermore, when novel sounds (but not standards) constitute valid warning cues, facilitation (instead of distraction) is observed.

In this study, we probed further the fundamental nature of behavioral novelty distraction by giving heed to another pivotal, yet unfathomed, issue: What is the nature of the change brought by novel auditory stimuli? We delineate below three hypotheses and report an experiment designed to disentangle them.

1.1. The base-rate probability hypothesis

Low base-rate probability, also referred to as rarity or novelty, has traditionally been the key definition of a novel or oddball stimulus. 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 novelty distraction, the base-rate probability hypothesis predicts that any sound of low base-rate probability, presented in the context of another (frequent) sound, should yield novelty distraction.

1.2. The expectation hypothesis

Novel sounds are not only *rare* but also *unexpected*. Probability and predictability are often used interchangeably in oddball studies but these concepts are not synonymous. In oddball tasks, the frequent occurrence of the standard might result in the expectation by the cognitive system, on any given trial, of another standard rather than of a novel sound. Novel sounds might therefore capture attention because they violate the cognitive system's expectation about upcoming events. The violation of predictions is increasingly emerging as an alternative to the trace-mismatch account of MMN (Winkler, 2007). In line with this view, unexpected stimulus omissions elicit MMN (e.g., Yabe, Tervaniemi, Reinikainen, & Näätänen, 1997), as does the violation of incidentally learned rules about perceptual transitions (Schröger, Bendixen, Trujillo-Barreto, & Roeber, 2007; van Zuijen, Sussman, Winkler, Näätänen, & Tervaniemi, 2005). According to the expectation hypothesis, a sound should distract participants in the cross-modal oddball task whenever it violates the participant's expectation, irrespective of whether that sound is frequent or not.

1.3. The local perceptual change hypothesis

While the first two hypotheses relate to the frequency of occurrence of the standard and novel sounds, a third hypothesis can be put forward: A novel may capture attention because it differs perceptually from the preceding stimulus, in a similar way as, for example, *changing* irrelevant sounds disrupt serial memory (e.g., Jones & Macken, 1993). Numerous studies showed that memory for sequences of visually presented stimuli is disrupted by the presentation of a to-be-ignored sequence of sounds but only when this sequence consists of changing segmented entities (e.g., Jones & Macken, 1995; Jones, Madden, & Miles, 1992), an effect functionally distinct from the effect of auditory deviants (Hughes, Vachon, & Jones, 2007). According to the local perceptual change hypothesis, distraction should be observed whenever change occurs from one trial to the next, irrespective of the sounds involved, and regardless of their base-rate probability and predictability.

1.4. The present study

To disentangle the above hypotheses, we used a cross-modal oddball task in which participants categorized the parity of visually presented digits. Each digit was preceded by an auditory stimulus that participants were instructed to ignore. The original characteristic of our task resided in the specific organization of the standard and novel trials. The standard sound S (a sine-wave tone) was used in 75% of trials while the novel sound N (burst of white noise) was presented in the remaining 25%. The novel trials were organized so that 8 out of 9 novels would form pairs of consecutive trials among otherwise randomly dispersed standard trials.

As visible from the top panel of Fig. 1, this manipulation created six types of trials: standard following another standard (S, or baseline), first novel of a pair of novels ($N_{1/2}$), second novel of a pair of novels ($N_{2/2}$), isolated novel ($N_{1/1}$), standard following an isolated novel (S_N), and standard following a pair of novels (S_{NN}).

Before we present the specific predictions related to the three hypotheses described earlier, two pertinent points deserve a mention. First, our experiment relied on the cognitive system's ability for incidental learning (e.g., Kaufman et al., 2010; Reber, 1989). Such ability has been observed in a variety of tasks, from the incidental learning

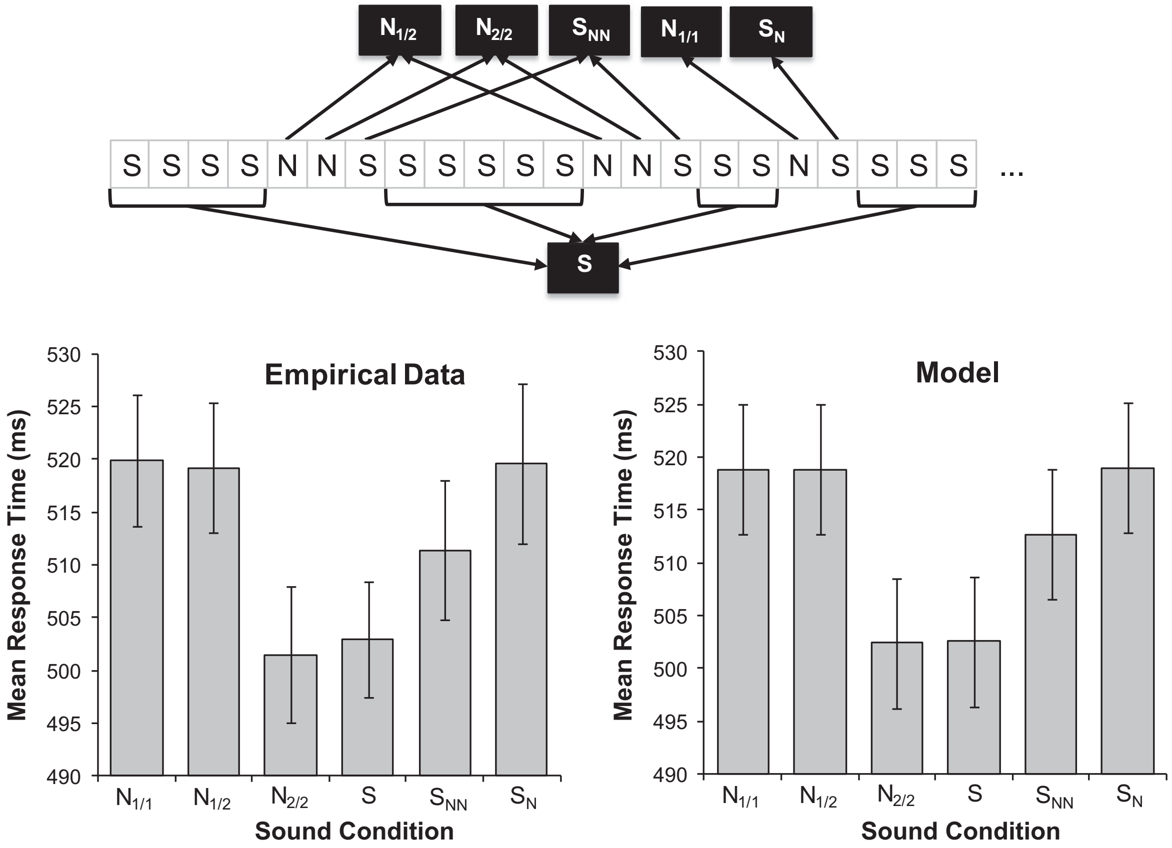

Fig. 1. Top panel: Schematic illustration of the six experimental conditions (see text for a description) created by the sequential presentation of trials involving the standard sound (S) and the novel sound (N). Bottom left panel: Mean response times for correct responses in the six sound conditions of the visual categorization task. Right bottom panel: Mean response times predicted from a model based on base-rate probability, auditory predictability and perceptual change. Error bars represent one standard error of the mean.

of artificial grammars of letter strings (e.g., Dienes, Broadbent, & Berry, 1991) or sounds (e.g., Altmann, Dienes, & Goode, 1995), to the progressive speeding up of motor actions in response to surreptitiously repeated sequences of stimuli (e.g., Destrebecqz & Cleermans, 2001; Howard & Howard, 1997; Nissen & Bullemer, 1987). Evidence shows that humans, even from a very young age, are capable of learning the statistical relationship between sequential events (e.g., Aslin, Saffran, & Newport, 1998; Conway, Bauernschmidt, Huang, & Pisoni, 2010; Saffran, Newport, & Aslin, 1996). This is typically demonstrated in the so called statistical learning task in which participants are exposed to a statistically structured sequence of sounds while performing another task and then asked to identify words conforming to the incidentally learned statistical regularities (e.g., Creel, Newport, & Aslin, 2004, see Saffran, Johnson, Aslin, & Newport, 1999, for a similar evidence using pure tones). The crucial point here is that these studies testify to the fact that participants not only learn the relative frequency of stimuli but also, and most critically for our purpose, the predictive relationship between them. In other words, participants incidentally learn and use knowledge about co-occurrence rates or conditional probabilities.

The latter observation naturally brings us to the second important point: the distinction between base rate and conditional probabilities. The base-rate probability of a stimulus is the probability of occurrence of that stimulus irrespective of other stimuli. Base-rate probabilities are crucial to the novelty account: A rare event (novel sound), by clashing with the memory trace of a frequent one (standard), triggers the orientation of attention towards novelty. The expectation hypothesis, on the other hand, posits that the cognitive system uses its incidental knowledge of conditional probabilities to predict future events. A conditional probability is the probability of a stimulus given one or several other stimuli. In oddball tasks, given a standard sound, the probability of another standard sound is much greater than that of a novel sound. Following a standard, the cognitive system will therefore expect another standard. The occurrence of a novel violates this expectation and it is this violation, not the novel sound's rarity *per se*, that is responsible for behavioral distraction. Our study is unique in contrasting base rate and conditional probabilities orthogonally, rendering it possible for the first time to create situations in which a rare event is predictable and a frequent one is unexpected. In order to make clear the distinction between the base rate and conditional probabilities in the context of this study, we report in Table 1 both types of probabilities for each of our experimental conditions.

Based on the above, a distinct pattern of predictions was derived from each of the three hypotheses outlined above. The base-rate probability hypothesis predicted that

Table 1
Base rate [$p_{(i)}$] and conditional [$p_{(i|(i-2)(i-1))}$] probabilities for the current sound (i), which was either the standard (S) or the novel (N) sound, in each of the 6 experimental conditions. Probabilities are rounded up to two decimals and are calculated on the 1512 test trials. The first two test trials (always standard trials) were counted as standards following two standards since test trials were preceded by standard practice trials.

Condition	Two preceding sounds ($i-2$, $i-1$)	Current sound (i)	$p_{(i)}$	$p_{(i|(i-2)(i-1))}$
S	SS	S	.75	.81
$N_{1/2}$ and $N_{1/1}$	SS	N	.25	.19
$N_{2/2}$	SN	N	.25	.80
S_N	SN	S	.75	.20
S_{NN}	NN	S	.75	1

all novels ($N_{1/2}$, $N_{2/2}$, $N_{1/1}$) should yield similar RTs, longer than for the different types of standard (S, S_N, S_{NN}), which should not differ for each other. As the base rates of the standard and novel sounds remain .75 and .25, irrespective of the immediately preceding sounds, any novel sound, by virtue of clashing with the neural model of the most frequent sound (standard), should yield distraction. Predictions from the expectation hypothesis were based on the calculation of conditional probabilities, and more precisely the probability of a sound given the two immediately preceding sounds (see Table 1). The rationale here was that the most probable sound given the two preceding sounds would be that predicted by the cognitive system. Longer RTs were predicted in response to all sounds violating the cognitive system's expectation, that is, to sounds with low conditional probabilities ($N_{1/2}$, $N_{1/1}$, S_N). In contrast, shorter RTs were predicted in response to predictable sounds, that is, sounds defined by high conditional probabilities (S, S_{NN}, $N_{2/2}$). Finally, the local perceptual change hypothesis predicted long RTs whenever a sound differs from the preceding sound ($N_{1/2}$, $N_{1/1}$, S_N, S_{NN}) and short RTs when they do not (S, $N_{2/2}$).

2. Experiment

2.1. Method

2.1.1. Participants

Twenty (14 women) undergraduates from the University of Plymouth took part in this experiment in exchange for a small honorarium. Participants were between 18 and 44 years of age ($M = 24.2$, SD = 6.4). All participants reported normal or corrected-to-normal vision and normal hearing.

2.1.2. Stimuli, design and procedure

Participants were presented with a total of 1512 test trials (organized in six blocks of 252 each). In each trial, they categorized a visual digit (1–6) as odd or even using two arbitrary allocated keys (counterbalanced across participants). These digits were presented in random order (different for every participant) but with equal probabilities across the task, at the center of the screen, sustaining a viewing angle of approximately 2.6°. Each digit was presented for 200 ms and preceded by a 200 ms sound with an SOA of 300 ms. Two sounds were used throughout the experiment. The *standard* was a 600 Hz sine-wave tone. The *novel* sound was a burst of white noise. Both sounds were normalized and edited to include 10 ms rise and fall ramps. Sounds were delivered binaurally through headphones at an intensity of approximately 75 dB. Upon the offset of each visual digit, participants had a further 1200 ms to respond before the next trial began. A fixation cross was present at the center of the screen throughout each trial, except during the presentation of the visual digits.

In 1134 trials (75%), the visual digit was preceded by the standard sound, while in the remaining 378 (25%) it was preceded by the novel sound. The novel trials were distributed within each block so that eight out of nine novels were presented on two consecutive trials (the remaining novel was preceded and followed by a random number of standard trials). Thus out of every five novel trials preceded by a standard trial, four were followed by another novel trial. A unique stimuli set obeying these rules was generated for each participant, resulting in six conditions (see Fig. 1, top panel): standard following another standard (S, 924 trials), first novel of a pair of novels ($N_{1/2}$, 168 trials), second novel of a pair of novels ($N_{2/2}$, 168 trials), isolated novel ($N_{1/1}$, 42 trials), standard following an isolated novel (S_N, 42 trials), and standard following a pair of novels (S_{NN}, 168 trials). The first two test trials always involved the standard sound.

Eight practice (standard) trials were presented at the beginning of each block. Participants used the Z and X keys on the computer keyboard to respond using two fingers from their dominant hand. The mapping between responses and keys was counterbalanced across participants. Testing took place in a quiet room. Instructions emphasized the need for both speed and accuracy.

3. Results

Hit rates and mean response times for correct responses were analyzed using a one-way ANOVA for repeated measures with the sound condition as the independent factor ($N_{1/1}$, $N_{1/2}$, $N_{2/2}$, S, S_N, S_{NN}). Hit rates were overall high ($M = .869$, SD = .102) and did not vary across conditions, $F(5, 95) < 1$, $MSE = .002$, $p = .736$, $\eta_p^2 = .028$. Response times, in contrast, varied significantly across conditions, $F(5, 95) = 5.555$, $MSE = 263$, $p < .001$, $\eta_p^2 = .226$. As visible from Fig. 1 (bottom left panel), response times were longest in the $N_{1/2}$, $N_{1/1}$ and S_N conditions (which yielded similar response times), shortest in the S and $N_{2/2}$ conditions (which resulted in comparable response times) and intermediate in the S_{NN} condition. Planned contrasts confirmed these observations. In line with all three hypotheses, response times were significantly longer in the $N_{1/1}$ and $N_{1/2}$ conditions compared to the standard (S) condition, $F(1, 19) = 17.133$, $MSE = 168.907$, $p < .001$, and $F(1, 19) = 19.828$, $MSE = 133.727$, $p < .001$ respectively. In line with the expectation and perceptual change hypotheses but clashing with the base rate hypothesis, response times were significantly shorter in the $N_{2/2}$ compared to the S_N, $N_{1/1}$ and $N_{1/2}$ conditions, $F(1, 19) = 6.882$, $MSE = 478.953$,

$p < .05$, $F(1, 19) = 18.759$, $MSE = 181.204$, $p < .001$, and $F(1, 19) = 30.630$, $MSE = 102.388$, $p < .001$, respectively. Furthermore, response times in the S_N condition were similar to the $N_{1/1}$ and $N_{1/2}$ conditions, $F(1, 19) < 1$, $MSE = 678.519$, $p = .973$, and $F(1, 19) < 1$, $MSE = 489.355$, $p = .950$, respectively, but significantly longer than in the S condition, $F(1, 19) = 5.079$, $MSE = 551.065$, $p < .05$. Finally, contrasts confirmed that response times in the S_{NN} condition fell significantly below the combined peaks of the $N_{1/1}$, $N_{1/2}$ and S_N condition, $F(1, 19) = 6.864$, $MSE = 145.512$, $p < .05$, but higher than in the S and $N_{2/2}$ conditions, $F(1, 19) = 6.888$, $MSE = 164.837$, $p < .05$.

3.1. Modeling response times

In order to assay the roles of base rate, expectation and perceptual change in our data and to model response times in our task, we used a regression model in which the dependent variable was the mean RT for each participant and condition in our experiment (i.e., 120 means) and in which there were four independent variables (see Maybery, Parmentier, & Jones, 2002; Parmentier & Maybery, 2008, for examples of this approach). The first parameter of the model, aimed to capture inter-individual differences, was the mean response time per participant. The remaining three parameters coded for the roles of novelty, expectation and perceptual change and took binary values. A parameter was set to 1 when a factor was hypothesized to predict behavioral distraction (0 otherwise). For example, parameters for condition $N_{2/2}$ were set to 1, 0 and 0 for the base rate, expectation and perceptual change factors respectively. The model accounted for most of the RT variance, $R^2 = .934$, $F(4, 115) = 404.46$, $p < .001$. Inter-individual variations contributed significantly to the model's goodness of fit, $B = 0.999$, $t(115) = 39.804$, $p < .001$, as did expectation, $B = 8.599$, $t(115) = 1.990$, $p < .05$, and perceptual change, $B = 8.899$, $t(115) = 2.059$, $p < .05$, but base rate did not, $B = -0.658$, $t(115) = -0.215$, $p = .830$. As can be seen from Fig. 1 (bottom right panel), our model produced a pattern of RTs strikingly similar to our empirical data, capturing all our key findings, including the intermediate mean RT in the S_{NN} condition.

4. Discussion

We measured the behavioral distraction yielded, in an ongoing visual categorization task, by the presentation of rare and unexpected changes in a sequence of auditory distracters. The pivotal manipulation consisted of the careful ordering of trials involving standard (tone) and novel (white noise) sounds with the aim of establishing whether novel sounds yield behavioral distraction because they are rare, because they violate the cognitive system's expectations, or because they involve a perceptual change from the previous sound. Our results can be summarized as follows. First, contrary to the predictions of the base-rate probability hypothesis, distraction was not systematically induced by the novel sound. Indeed, performance following a predictable novel ($N_{2/2}$) was comparable to that in the standard condition S while an unexpected standard sound (S_N) produced as much distraction as unexpected novels ($N_{1/1}$ and $N_{1/2}$). These findings matched the predictions of both the expectation and perceptual change hypotheses. The critical condition to disentangle the latter two hypotheses was the S_{NN} condition, that is, the condition in which a standard trial followed two consecutive novel trials. In that condition, the standard sound was predictable while inducing a perceptual change from the previous trial. Response times in that condition were significantly shorter than in the conditions in which the sound was not predictable ($N_{1/1}$, $N_{1/2}$, S_N), in line with the expectation hypothesis but clashing with the perceptual change hypothesis. However, response times in that condition were also significantly longer than in the conditions in which the sound was predictable (S, $N_{2/2}$), in line with the perceptual change hypothesis but contradicting the expectation hypothesis. In sum, results from the S_{NN} condition suggest that both expectation and perceptual change may contribute to distraction. In line with this contention, a model based on expectation and perceptual change, produced a remarkably close fit to our empirical data and captured all our findings.

Our results evidenced an effect of perceptual change, even when predictable (S_{NN}). Two potential explanations can be proposed for this effect. The first is that the transitory perceptual difference between the previous stimulus' memory trace and the current sound yields disruption, reminiscent of the general detrimental effect yielded by task-irrelevant changes observed in recognition studies when study and test stimuli are presented in different contexts (e.g., Isarida & Isarida, 2007; Maybery et al., 2009; Pascalis, Hunkin, Bachevalier, & Mayes, 2009; see Kawahara, 2007; Pescara-Kovach, Fulkerson, & Haaf, 2000, for studies using visual stimuli in an auditory context). Distraction in the S_{NN} condition converges with reports of behavioral distraction on the first standard trial following a novel trial in auditory and auditory-visual oddball tasks (Ahveninen et al., 2000; Berti, 2008; Parmentier & Andrés, 2010; Roeber, Widmann, & Schröger, 2003). Our results suggest that it cannot be reduced to residual distraction lingering from the preceding novel trial since, in our study, distraction occurred on the standard trial following a novel trial yielding no distraction. Tentatively, one may propose that a local perceptual change elicits some degree of distraction. In line with this contention, some studies reported a small but significant MMN response on post-deviant standard trials in passive listening tasks (Nousak, Deacon, Ritter, & Vaughan, 1996; Sams, Alho, & Näätänen, 1984), as well as P3a and RON responses on such trials in a tone duration judgment task (Roeber, Berti, Widmann, & Schröger, 2005; Roeber et al., 2003).

The second potential account of the distraction observed in the S_{NN} condition relies on the involuntary extraction of a local rule. While some studies suggest that several repetitions of a sound are necessary for a neural model of the standard to develop (e.g., Cowan, Winkler, Teder, & Näätänen, 1993; Sams et al., 1984), others demonstrate the existence of rapid rule extraction mechanisms (Bendixen & Schröger, 2008; Haenschel, Vernon, Dwivedi, Gruzelier, & Baldeweg, 2005). For example, Bendixen, Roeber, and Schröger (2007) cogently demonstrated that a single repetition of a stimulus is sufficient for the cognitive system to extract a *local* rule and for MMN to occur when this local rule is violated. The reduction of MMN on the second deviant of a pair of deviants suggests that the system evaluates the informational value of the repetition (Müller & Schröger, 2007; Müller, Widmann, & Schröger, 2005). The extraction of a local rule may potentially have been facilitated in our study by the fact that conditional probabilities predicted the occurrence of N following another N. This contention converges with the absence of MMN on the second deviant of a pair of deviants in an experimental context in which deviants always occur in pairs (Sussman & Winkler, 2001; Sussman et al., 2002). In our task, while S was entirely predictable following NN on the basis of task-wide conditional probabilities, it may nevertheless have violated a locally defined rule and resulted in distraction.

In conclusion, our study adds to previous knowledge on behavioral novelty distraction by demonstrating for the first time that, within the circumstances promoting distraction (Parmentier, Elsley, & Ljungberg, 2010), novel sounds do not capture attention by virtue of their rarity but rather because they violate the cognitive system's expectation and clash with the perceptual trace from the previous auditory stimulus (a clash that may itself violate locally defined rules). This finding fits with pithy electrophysiological evidence of rule violation detection (Horváth, Czigler, Sussman, & Winkler, 2001; Paavilainen, Arajärvi, & Takegata, 2007; Paavilainen, Simola, Jaramillo, Näätänen, & Winkler, 2001; Schröger et al., 2007) and more generally with the concept of a proactive brain extracting rules from past events in order to predict future events (Bar, 2007; Schröger et al., 2007; Winkler, 2007).

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