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Broken Expectations: Violation of Expectancies, Not Novelty, Captures Auditory Attention

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The role of memory in behavioral distraction by auditory attentional capture was investigated: We examined whether capture is a product of the novelty of the capturing event (i.e., the absence of a recent memory for the event) or its violation of learned expectancies on the basis of a memory for an event structure. Attentional capture—indicated by disruption of a focal visually presented serial recall task—was found when the voice conveying a concurrent irrelevant auditory sequence changed every 5 recall trials (from male to female or vice versa). There was no evidence of attentional capture when the irrelevant sequence was first encountered and hence novel; capture occurred only when an expectation for a particular voice had been learned and then violated. Furthermore, with the increasing predictability of (and hence expectancy for) the voice changes across the experimental session, the capture response diminished only to be reinstated when that session-wide expectation was itself violated by a break in the change-every-5-trials pattern. The results highlight the critical role of learned expectations, as opposed to novelty detection, in behavioral auditory attentional capture.

Keywords: learned expectancies, auditory attention, attentional capture, auditory distraction, expectancy violation

The capacity for having attention captured away from a prevailing activity is a critical characteristic of the cognitive system: Whereas the absence of such distractibility would confer the apparent advantage of being able to focus inexorably on a chosen goal, it would also mean a maladaptive lack of responsiveness to changing circumstances, some of which could signal danger or opportunity (see, e.g., Allport, 1989; Johnston & Strayer, 2001; Neumann, 1987). At the same time, distractibility must be constrained so that attention is not diverted too readily, lest the individual be too much at the mercy of external stimuli. The present article is concerned with the role of memory in striking the appropriate balance between attentional selectivity and behavioral distractibility. Specifically, we ask: Does an event capture attention to the extent that there is no recent memory for that event (i.e., its novelty or unfamiliarity), or, instead, to the extent that it violates an expectation based on the learning of a preceding pattern of stimulation? Using a methodology in which attentional capture is measured through the disruptive effects of irrelevant auditory events on an unrelated, visually presented, short-term recall task (see, e.g., Hughes, Vachon, & Jones, 2005, 2007; Lange, 2005; Sörqvist, 2010), we present evidence that favors the expectancy-violation account over the novelty-detection account.

Attentional capture may be defined as an exogenous orienting of the attentional focus away from a prevailing mental activity due to the detection of task-irrelevant stimulation that is perceived as being worthy of further evaluation (see, e.g., Johnston & Strayer, 2001). One class of stimulus that tends to capture attention is that in which the stimulus itself is either significant personally (e.g., one's own name; Moray, 1959), is intense or has a sudden onset, or matches some transient mental set (e.g., a picture of a meal for a hungry person). In contrast to these forms of attentional capture, our interest here centers on aspecific attentional capture in which there is nothing inherent to the content of the eliciting stimulus itself that endows it with attention-capturing power. Rather, it captures attention because it differs in some way from the prevailing context (for further discussion of the specific vs. aspecific distinction, see Eimer, Nattkemper, Schröger, & Prinz, 1996). For example, a B tone following a standard A tone—whether that change is transient (AAAABAA) or enduring (AAAABBB)—will tend to capture attention, as shown by its disruption of an unrelated focal task (see, e.g., Escera, Alho, Winkler, & Näätänen, 1998; Hughes, Vachon, & Jones, 2005, 2007; Lange, 2005; Parmentier, Elford, Escera, Andrés, & San Miguel, 2008; Schröger & Wolff, 1998; Sörqvist, 2010). Such auditory deviations also elicit distinct

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components of the auditory event-related potential (ERP; e.g., mismatch negativity [MMN] and the P3a) which are typically interpreted as neural markers of the attentional capture process (for a review, see Näätänen, Tervianiemi, Sussman, Paavilainen, & Winkler, 2001).

One possible mechanism underpinning distraction by (aspecific) auditory attentional capture is novelty detection: A stimulus captures attention if it is new or relatively rare in relation to the recent history of stimulation. This *novelty-detection account* has its roots in some classical theories of the preconditions for the orienting reflex or response (OR) and its habituation (see, e.g., Cowan, 1995, p. 140; Sokolov, 1963; Voronin & Sokolov, 1960). The OR encompasses physiological responses (e.g., increased skin conductance, heart rate deceleration), motor responses (e.g., head and eye movements), and psychological (an involuntary shift of attentional focus) responses to a novel stimulus (Pavlov, 1927; Sokolov, 1963). Importantly, the OR is assumed to habituate with repeated presentation of the initially novel stimulus, as a memory for, or *neuronal model* (Sokolov, 1963) of, the physical features of the repetitive stimulus is gradually established (see, e.g., Cowan, 1995; Gati & Ben-Shakhar, 1990; Öhman, 1979; Sokolov, 1963). Thus,

> when a stimulus is presented, a comparator looks for a match between the sensory input and a neuronal model. If there is no match, the [OR] response is triggered. But if the comparator detects a match the OR is inhibited. (Hall, 1991, p. 29)

Importantly, therefore, as noted previously in a critique by Näätänen (1990, p. 266; see also Öhman, 1979), on this account of attentional capture "what is essential is the *lack of* a neuronal model corresponding to the [capturing] stimulus" (emphasis added; see also Schröger & Wolff, 1998).

However, despite its elegant simplicity, it has long been recognized that the novelty-detection account, and the poor-or-lack-of-neuronal-model mechanism upon which it is based, copes only with a restricted range of circumstances. For instance, it has been found that the *8* in the spoken sequence "1234568 . . ." elicits an OR but that the *6*, say, does not, even though both stimuli are equally physically novel, that is, stimuli for which, in both cases, a neuronal model is lacking (Unger, 1964). Moreover, not only does the B in AAAAAA*B* capture attention but it also does so when repeated in the sequence ABABAB*B* (Nordby, Roth, & Pfefferbaum, 1988; see also Hughes et al., 2007). In this latter case, the B stimulus captures attention despite the fact that a neuronal model of that stimulus would be at least as well specified as the neuronal model for all preceding stimuli. In short, these two types of observations suggest that novelty is, respectively, neither sufficient nor necessary for attentional capture (Näätänen, 1986; Unger, 1964; Velden, 1978).

Auditory attentional capture effects—including those just described that are problematic for the novelty-detection account—seem to be better explained by an *expectancy-violation* account. On this account, the precondition for the OR, including behavioral attentional capture, is the violation of an abstract forward (or predictive) model based on any invariance characterizing the unfolding sequence (see, e.g., Cowan, 1995, e.g., p. 163; Hughes, Vachon, & Jones, 2005, 2007; Näätänen, 1990; Schröger, 1997; Schröger, Bendixen, Trujillo-Barreto, & Roeber, 2007; Sokolov, 1975; Winkler, Denham, & Nelken, 2009). Based to date mainly on auditory ERP studies, a wide range of pattern rules—from local rules (i.e., relations between temporally adjacent stimuli) to global rules (i.e., relations between temporally nonadjacent stimuli; see, e.g., Horváth, Czigler, Sussman, & Winkler, 2001; Schröger, 1997)—have been found to be preattentively extracted. The formation of a model of the rule(s) governing the organization of an auditory sequence allows implicit inferences (or expectancies) to be derived about future events. Rule-based expectancies cannot, logically, be derived without a certain buildup, that is, the presentation of a few stimuli that form some regular pattern (see, e.g., Bendixen, Roeber, & Schröger, 2007; Sams, Alho, & Näätänen, 1984). Thus, in this view, it is not the absence of a memory for the capturing event that is key (as in the novelty-detection account) but rather the presence in memory of a pattern of events into which the capturing event does not fit (Näätänen, 1990).

Of particular relevance to cognitive theory, several cognitive models of auditory selective attention invoke habituation of the OR as the selective filtering mechanism (cf. Broadbent, 1958): Habituation of the OR through stimulus repetition (or continuation) allows attentional resources to be deployed undiminished to the focal task unless a novel event is detected within the unattended scene (see, e.g., Cowan, 1995; Elliott & Cowan, 2001; Lange, 2005; Mackworth, 1969; Waters, McDonald, & Koresko, 1977). At the neural level, this habituation process is instantiated as a differential state of refractoriness of afferent elements for novel compared with less novel stimuli as reflected in the N1 component of the auditory ERP; yet, another mechanism, indexed by the MMN, has been identified as being responsible for the detection of an irregular (or deviant) event through a mismatch between that event and a record of any invariance embodied in the recent auditory context (see, e.g., Näätänen, 1990; Schröger & Wolff, 1998; Sokolov, Spinks, Näätänen, & Lyytinen, 2002). The key observation motivating the present research is that although the distinction between the novelty-detection-based mechanism and that of expectancy violation has been discussed in the context of psychophysiological studies of the OR and its ERP correlates (see, e.g., Näätänen, 1990; Schröger & Wolff, 1998; Velden, 1978), it has been less prominent in the cognitive behavioral literature (see, e.g., Cowan, 1995; Dalton & Lavie, 2004; Elliott & Cowan, 2001; Lange, 2005; Parmentier, 2008; Waters et al., 1977; but see Hughes, Vachon, & Jones, 2005, 2007; Parmentier, Elsley, Andrés, & Barceló, 2011). In glossing over this distinction within the cognitive–behavioral literature, behavioral attentional capture by stimulus novelty (i.e., a rare or relatively unfamiliar stimulus) and by stimulus deviance (i.e., an expectancy-violating stimulus)—and the different types of neuronal models upon which such instances of capture are based—have tended to be conflated. In fact, the concepts of deviance and novelty have often been used as synonyms for one another (see, e.g., Tiitinen, May, Reinikainen, & Näätänen, 1994). One likely reason for this is that a novel stimulus (e.g., the B in AAAAB) typically also violates expectancies and hence in such cases the possible independent role of novelty per se cannot be deduced. In the present study, therefore, we examined whether expectancy violation or novelty plays the key role in behavioral auditory attentional capture during an unrelated focal cognitive task.

We capitalize on a recently established phenomenon whereby a focal visually presented serial recall task was found to be highly sensitive to disruption by infrequent changes in task-irrelevant auditory stimulation (Hughes, Vachon, & Jones, 2005, 2007; Lange, 2005; Sörqvist, 2010). Here, a visual–verbal list of around six to eight items such as letters or digits is visually presented, and participants must recall the items in strict serial order. The presentation of the to-be-remembered list is accompanied by a to-be-ignored auditory sequence (usually speech). Previous work has established that the presentation of a single deviant auditory event within the auditory sequence (e.g., a single word spoken in a different voice from that conveying the remaining words) captures attention as indexed by its disruption of serial recall (Hughes, Vachon, & Jones, 2005, 2007). However, as noted, findings from studies using single, infrequent deviants (or "oddballs"; see also, e.g., Parmentier et al., 2008; Schröger, 1997) do not allow one to tease apart the novelty-detection and expectancy-violation accounts, because the capturing sound could assume its potency from the lack of opportunity to build up a sufficiently well-specified neuronal model of that sound (given its relative infrequency) or, equally, because it deviates from an expectancy for the standard sound (Niepel, 2001; Schröger & Wolff, 1998; though see Parmentier et al., 2011).

Due to this problem with the interpretation of the effects of single deviant events, we used a "roving standard" procedure (see, e.g., Elliott & Cowan, 2001; Lange, 2005), one in which the same irrelevant auditory stimulus—an auditory sequence in this case—served, at different times, as both standard and deviating stimulus. This may be represented schematically as AAAA*B*BBBB*A*AAAA*B*BBBB, where the italicized event represents a deviation. Thus, across the experiment, the stimulus event serving as the deviating event is no more or less frequently encountered than the stimulus serving as a standard. Specifically, on each trial, an auditory sequence composed of letter names conveyed in a given voice (e.g., a female voice) was presented concurrently with a visual list of digits presented for serial recall. Every five serial recall trials, a change—and hence potentially attention-capturing event—occurred: The voice conveying the irrelevant letters changed from female (F) to male (M) or vice versa (i.e., FFFFFMMMMMFFFFF). This roving standard design allows two ways of adjudicating between the novelty-detection and expectancy-violation accounts. As noted, according to the novelty-detection account, the precondition for attentional capture is the lack of a neuronal model of the critical event (see, e.g., Cowan, 1995; Öhman, 1979; Voronin & Sokolov, 1960) rather than the presence of a mismatching model (Näätänen, 1990). One key line of support for the novelty-detection view is that the classical OR is elicited typically by the first stimulus in a sequence (the *initial OR*; O'Gorman, 1979) and not only by a change within a sequence (the *change OR*), because a neuronal model of both an initial stimulus and a new stimulus is lacking: "According to OR theory, the cerebral initiation of the OR is basically the same for the first stimulus of a sequence and the stimulus change in that sequence" (Sokolov et al., 2002, p. 320; for a discussion, see Näätänen, 1986). Thus, a unique prediction of the novelty-detection account tested in Experiment 1 is that attentional capture as indicated by behavioral distraction should be evident on first encounter with the irrelevant material (e.g., on the first trial of the experiment) due to the absence of a neuronal model of the attributes of the irrelevant sequence. Such attentional capture would be demonstrated by relatively poor serial recall performance on the first trial followed by a recovery of performance as a neuronal model of that material is fabricated through its repetition over the next four trials. In contrast, from the standpoint of the expectancy-violation account, on the first trial, no potentially violable rule could have been established, and hence no disruption should occur until the sixth trial, that is, at the point at which the first change in the voice conveying the irrelevant stimuli is encountered and the expectation "every irrelevant sequence is presented in voice *x*" is violated.

A second prediction of the expectancy-violation account tested in Experiment 1 and scrutinized further in Experiment 2 is that an event that initially violates expectancies (e.g., a voice change) should cease to do so and thereby lose its attention-capturing power if that same event begins to be perceived as forming part of a larger repeating pattern and hence becomes expectable (see Meyer, Reisenzein, & Schützwohl, 1997). Specifically, in the present study, given that the across-sequence changes of voice occurred in a regular pattern—with a change every five trials—attentional capture by the voice changes should diminish over the course of the experiment as a neuronal model representing the temporally broader pattern ("the voice changes every five sequences/trials") envelops and supersedes the initial local rule-based neuronal model ("all sequences are presented in voice *x*").

Experiment 1

Method

Participants. Thirty-seven undergraduate psychology students at Cardiff University, all reporting normal or corrected-to-normal vision and normal hearing, participated in the experiment in return for course credit.

Apparatus and stimuli.

The focal task. The to-be-remembered visually presented sequences were eight items in length and were taken without replacement from the digit set 1–9 and arranged in a quasirandom order, with the constraint that successive digits were not adjacent integers. Each item was approximately 2.5 cm in height and presented sequentially in Times New Roman font at the center of the screen of a computer running E-Prime 1.1 (Psychology Software Tools). Each digit was presented for 350 ms, and the interstimulus interval (offset to onset) was 400 ms.

The irrelevant sequences. The irrelevant auditory sequences consisted of the letters *A B C G J K L M Q S* (presented in a different random order on each trial), all spoken in a female voice or all spoken in a male voice. All irrelevant speech stimuli were edited using the Sound Forge (Sony Creative Software) software such that each lasted 250 ms. The interstimulus interval within an irrelevant speech sequence was 350 ms. Within each voice, each item was spoken at an approximately even pitch, and care was also taken to ensure that all auditory stimuli, regardless of voice gender, were presented at approximately 65 dB (A). The onset of the first speech sound preceded the onset of the first visual digit by 125 ms (cf. Hughes et al., 2007).

Design and procedure. Figure 1 illustrates the structure of Experiment 1. There were 90 trials divided into 18 subgroups of five trials each (hereafter: quintets). Each trial of a given quintet was accompanied by the same type of irrelevant sequence, either female voice or male voice. Quintets of female-voice and male-voice trials were alternated throughout a single block of 90 trials.

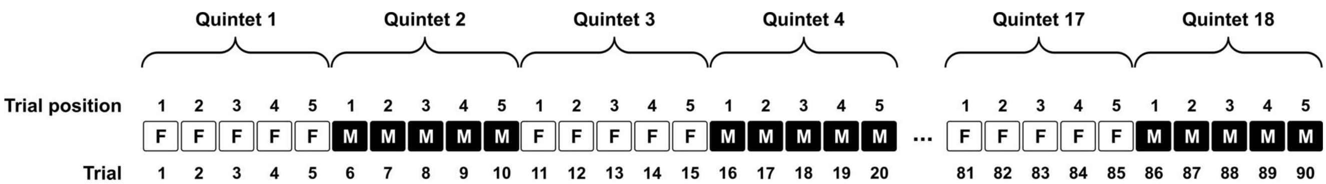

Figure 1. Schematic representation of the manipulation of the irrelevant speech sequences across trials of Experiment 1. Each of the five trials of a given quintet was accompanied by the same type of irrelevant sequence, either female voice (F) or male voice (M). Eighteen quintets alternated between the female and the male voice throughout a single block of 90 trials. Hence, a change of voice always occurred at Trial Position 1, except for in the first quintet.

Participants were tested individually in a sound-attenuated booth. They read standard instructions informing them of what the serial recall task involved and asking them to ignore any sounds presented over the headphones. They were not told about the changes of voice in the irrelevant sound. They were informed that the trials would be presented at a preset pace: 50 ms following the offset of the last visual item, the screen flashed from white to black for 150 ms, which signaled to the participants that they should begin to write out the to-be-remembered list. From the offset of the screen flashing, there was 15 s before the presentation of the first item of the next to-be-remembered list. Thirteen seconds into this 15 s of writing time, a 500-ms tone was presented over the headphones as a signal to the participants that the presentation of the first item of the next sequence was imminent. The first five trials (or first quintet) were accompanied by a female-voice irrelevant speech sequence, followed by five trials (i.e., the second quintet) with the male-voice irrelevant speech sequence type. Hence, the first change of voice occurred on Trial 6 (see Figure 1). The two types of irrelevant sequences continued to be alternated every five trials thereafter.

Results

In both experiments reported here, the raw data were scored according to the strict serial recall criterion as per convention: Recalled items were scored as correct only if they corresponded to their presentation position. Recall performance was assessed according to the within-subject factor trial position (one of the five possible positions of the trial within a quintet). Note that the voice conveying the speech (male vs. female) was not entered as a factor, because an initial analysis showed no effects of this factor.

We begin by addressing the basic question of whether the changes of voice captured attention, which would be indicated by a disruption of serial recall on Trial 1 of each quintet followed by a performance recovery across the remaining trials of each quintet. Thus, we examined performance for each trial position (1–5) collapsed across Quintets 2 to 18 (Quintet 1 was not included because no voice change occurred in this quintet). Figure 2 shows the mean percentage of correct recall for each trial position. It is clear that performance was poorer following a change of voice—that is, at Trial Position 1—and recovered between Trial Positions 2–5. This was confirmed by a repeated-measures analysis of variance (ANOVA), which revealed a significant main effect of trial position, $F(4, 144) = 14.33$, $p < .001$, $d = 1.26$, and a combination of significant linear, $F(1, 36) = 60.48$, $p < .001$, and quadratic, $F(1, 36) = 13.14$, $p = .001$, trends. Although no significant difference in correct recall was found across Trial Positions 2–5—which suggests that the voice-change effect was confined to Trial Position 1—the linear trend was still significant when Trial Position 1 was removed from the analysis (slope = 0.68%), $F(1, 36) = 5.29$, $p = .027$, suggesting a gradual performance recovery over the last four trial positions.

Having established that the voice change was endowed with attention-capturing power, we turn now to address the critical issue of whether the first encounter with the irrelevant material captured attention. An attentional response to the first irrelevant sound sequence (i.e., that presented on the first trial) would be indicated by improved performance across the remaining four trials in the first quintet (i.e., the same pattern as was found across the other quintets). Figure 3 shows the percentage of items correctly recalled for each trial of both the first and second quintets. In line with the expectancy-violation account, and at odds with the novelty-detection account, whereas there is a clear drop in performance for Trial Position 1 of the second quintet, followed by a recovery across Trial Positions 2–5 for that quintet (i.e., a microcosm of the pattern found when averaging across Quintets 2–18), critically, no such pattern is evident for the first quintet. This was confirmed by a 2 × 5 repeated-measures ANOVA carried out on correct recall with the factors quintet (first vs. second) and trial position (1–5). The main effect of quintet was not significant ($F < 1$), whereas that of trial position approached significance, $F(4, 144) = 2.28$, $p = .064$, $d = 0.50$. Most important, the interaction between quintet and trial position was significant, $F(4, 144) = 5.87$, $p < .001$, $d = 0.81$. This interaction arose because the effect of trial position was significant for the second quintet, $F(4, 144) = 7.66$, $p < .001$, $d = 0.92$, but not for the first quintet[1] ($F < 1$, $d < 0.11$).

[1] Serial recall performance is sometimes analyzed according to the serial position of each to-be-remembered item, whereas we collapsed the data across serial position for the sake of clarity. It could be argued that collapsing across serial position can prevent the detection of small attention-capture effects, for instance, at the serial position that is temporally closest to the voice change, that is, Serial Position 1. In order to rule out this possibility, we also examined the impact of trial position for the first two quintets of trials by restricting the analyses to the recall performance at Serial Position 1. The pattern of results was the same as when all serial positions were included. Indeed, the analysis revealed that the effect of trial position on performance at Serial Position 1 was not significant in the first quintet, $F(4, 144) < 1$, $d = 0.20$, whereas it was significant in the second quintet, $F(4, 144) = 5.09$, $p = .001$, $d = 0.75$. This result suggests that the absence of disruption of serial recall in the first trial of the experiment cannot be attributed to a lack of sensitivity ensuing from collapsing all serial positions together.

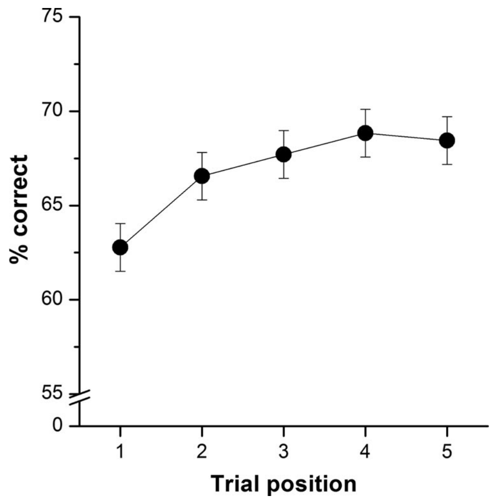

Figure 2. Results from Experiment 1: Mean percentage of items correctly recalled for each trial position (1–5). Data from the first quintet of trials are not included. Error bars represents 95% within-subject confidence intervals.

In fact, the only difference in performance between the first and second quintet was found at Trial Position 1, $t(36) = 3.30$, $p = .002$, $d = 1.10$.

Finally, we tracked the magnitude of the voice-deviation effect across the entire block of trials to test the further prediction of the expectancy-violation account that attentional capture by the voice change should wane over the experimental session as the pattern of voice changes becomes incorporated into a "higher order" rule-based neuronal model. We compared recall across Trial Positions 1–5 for Quintets 2–18 (i.e., all quintets except the first, which did not involve a voice change). To simplify the analysis, we derived two data points for each quintet, one representing the voice-change trial (i.e., Trial Position 1 of each quintet) and one representing non-voice-change trials (i.e., recall performance collapsed across Trial Positions 2–5 of each quintet). These data are plotted in Figure 4. A profile analysis was conducted to compare the profiles for Trial Position 1 and Trial Positions 2–5 across the 17 quintets of interest. With Wilks's criterion, the level test indicated that recall was significantly lower generally at Trial Position 1 ($\Lambda = .262$), $F(1, 36) = 101.66$, $p < .001$, and the significant flatness test indicated a general practice effect ($\Lambda = .179$), $F(16, 21) = 6.01$, $p < .001$. Most important, however, the profiles deviated significantly in terms of parallelism ($\Lambda = .297$), $F(16, 21) = 3.11$, $p = .008$, indicating that as the voice change became increasingly predictable, it lost its attention-capturing power. In fact, the potency of the voice change to attract attention seemed confined mainly to the first few such changes, because the parallelism test became nonsignificant when Quintets 2–4 were removed from the analysis ($\Lambda = .794$, $F < 1$). The results of a 2 × 17 repeated-measures ANOVA performed on correct recall with trial position (1 vs. 2–5) and quintet (2–18) were consistent with those of the profile analysis.

Discussion

The first noteworthy feature of the results of Experiment 1 is that a voice deviation implemented across irrelevant sequences (or across trials)—as opposed to a single deviation in voice within an irrelevant sequence found in other studies (e.g., Hughes et al., 2007)—captures attention as indexed by a disruption of the short-term memory task. Of greater theoretical interest, Experiment 1 also yielded two lines of evidence that converge to support the expectancy-violation over the novelty-detection account of auditory attentional capture. The first is that no disruption was evident when the irrelevant material was first encountered, even though at this point no neuronal model of the physical characteristics of that material could have been formed. This is clearly problematic for the novelty-detection account, in which, by definition, capture is a product of the newness of the stimulus as indicated by the absence (or impoverished state) of a neuronal model of that stimulus (see,

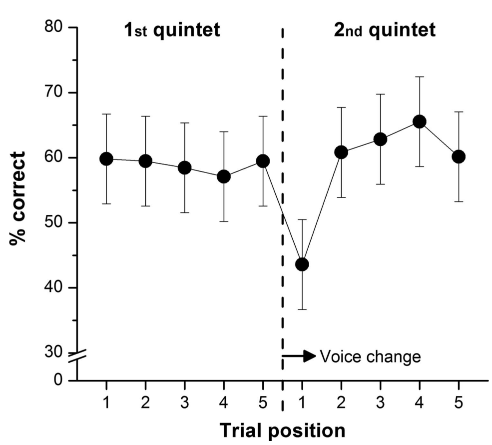

Figure 3. Results from Experiment 1: Mean percentage of items correctly recalled in each of the first two quintets of trials. The items that composed the irrelevant auditory sequence accompanying the to-be-remembered sequence were conveyed in a female voice for the first quintet and in a male voice for the second quintet so that a change of voice occurred at Trial Position 1 of the second quintet (illustrated by the dashed bar). Error bars represent 95% within-subject confidence intervals.

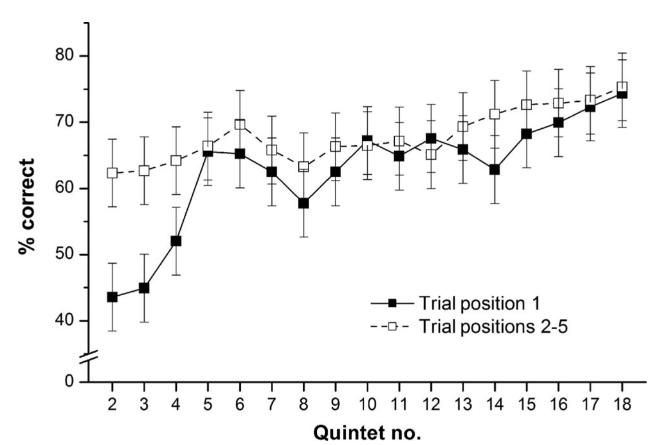

Figure 4. Results from Experiment 1: Mean percentage of items correctly recalled at Trial Position 1 and Trial Positions 2–5 (i.e., performance collapsed across Trial Positions 2–5) in Quintets 2–18. Error bars represent 95% within-subject confidence intervals.

e.g., Cowan, 1995; Gati & Ben-Shakhar, 1990; Öhman, 1979; Sokolov, 1963). Indeed, on the novelty-detection account, one might have expected, in contrast to the results obtained, the strongest capture effect to occur on the first trial of the first quintet compared with the first trial of each quintet thereafter, because on the very first trial none of the features of the irrelevant material could yet have been represented in a neuronal model. By Trial 1 of Quintet 2, there would, presumably, have been an opportunity to develop a neuronal model that at least incorporated the rhythm, item duration, and perhaps general nature of the distractors (spoken stimuli; see Elliott & Cowan, 2001). And yet there was a capture effect at this trial position but none on the very first trial. That a capture effect was found only when there was a deviation in the nature of the irrelevant stimulation is, however, entirely in line with the expectancy-violation account of attentional capture. On this account, some expectation has to be formed (e.g., "all irrelevant stimuli will be conveyed in a female voice") before that expectation can be broken (e.g., by the presentation of a male-spoken sequence) and thereby trigger an attentional-capture mechanism (see, e.g., Winkler, 2007).

A second strand of evidence in line with the expectancy-violation account is that the power of a voice change to capture attention diminished as the global pattern of voice changes (occurring every sixth trial) became predictable and hence expectable. Although there is evidence that the predictability of single deviant sounds can extinguish the attentional-capture response (see, e.g., Sussman, Winkler, & Schröger, 2003), it is the first time, to our knowledge, that such a predictability effect has been demonstrated for a pattern that is relatively large-scale, that is, one where the critical unit in the pattern is a quintet of auditory sequences lasting 105 s. This is readily explained by the notion that locally based rules can become obsolete as they are superseded by a higher order rule derived from a temporally broader invariance (cf. Horváth et al., 2001). The learning of a higher order rule did not seem to occur in a linear fashion in the present experiment, because no reliable disruption of serial recall was observed after the fourth quintet of trials (see Figure 4). Such an abrupt recovery could reflect a threshold-based application of attentional control over orienting as soon as a rule is learned. More work is required to better understand how memory representations of large-scale acoustic regularities become established over time and when such representations start serving as the basis to control attentional orienting, but these questions go beyond the scope of the present study.

Although the habituation of the attentional response over the course of the experiment is consistent with the expectancy-violation account, it may be argued that this aspect of the results could also be explained by the novelty-detection account, if it was supposed that neuronal models representing the characteristics of each voice became increasingly better specified as the session progressed, and hence with each quintet each voice would be perceived as less and less novel. In Experiment 2, therefore, as well as seeking to replicate the key findings of Experiment 1, we again examine the impact of voice changes across the experimental session but in such a way as to further tease apart the expectancy-violation and novelty-detection accounts.

Experiment 2

Experiment 2 was designed to determine whether the across-session habituation to capture by the voice change observed in Experiment 1 was attributable to the gradual integration of the across-session pattern of voice changes into a rule-based neuronal model (expectancy-violation account) or, alternatively, to the enhancement, through extended exposure, of neuronal models of the physical features of each voice (novelty-detection account). The device we adopted was to introduce an unpredictable break into the pattern of voice alternation. Late into the session, when a quintet of female-voice sequences was expected, a voice change (back to the male voice) was introduced at Trial Position 2. Specifically, as illustrated in Figure 5, following the "predictable" voice change (to a female voice) at Trial Position 1 of the 11th quintet—which should not capture attention at this point of the experiment (as already established in Experiment 1; see Figure 4)—an "unpredictable" change of voice (back to the male voice) occurred on the next trial (i.e., on Trial Position 2 of Quintet 11). The male voice then accompanied the remaining trials of Quintet 11. According to the expectancy-violation account, the change of voice on Trial Position 2 in Quintet 11 should reinstate the capture response because it would violate the higher order neuronal model (i.e., "a voice change occurs, and only occurs, every sixth trial"). In contrast, the novelty-detection account could not explain a voice-change effect at Trial Position 2 in Quintet 11 because the

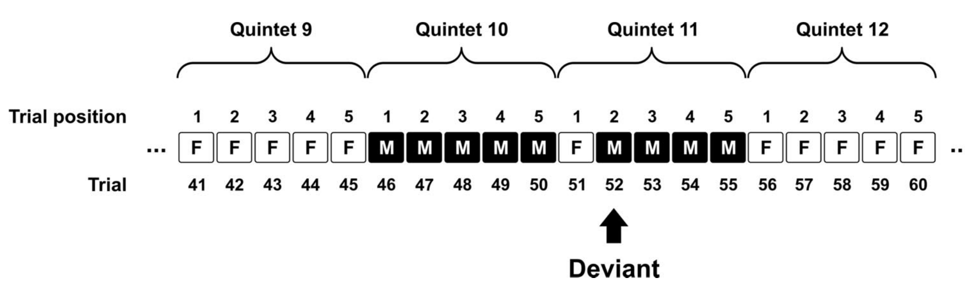

Figure 5. Schematic representation of the critical manipulation in Experiment 2. The first 10 quintets of trials alternated between the female voice (F) and the male voice (M) as in Experiment 1. The first trial of the 11th quintet consisted of a typical, hence predictable, change of voice, from male to female. An unpredictable change of voice, from female to male, occurred at Trial Position 2 in Quintet 11, and the male voice accompanied the three remaining trials of that quintet. From Quintet 12 to the end of the experiment, the across-quintet voice alternation pattern went back to normal.

novelty of the male voice would be relatively low by this point in the experiment, especially because the male voice would have recently been encountered for five trials in Quintet 10.

Another goal of Experiment 2 was to replicate the key findings from Experiment 1, namely, the absence of an attentional-capture effect on first encounter with the irrelevant stimulation (i.e., on the very first trial) and, up until Quintet 11, the across-session habituation of the attentional response to the voice changes.

Method

The method was identical to that of Experiment 1, except as noted in the next sections.

Participants. Twenty-four Cardiff University students who reported normal or corrected-to-normal vision and normal hearing received a small honorarium for their participation. None of the participants had taken part in Experiment 1.

Design and procedure. The single block of trials was reduced to 70 trials, divided into 14 quintets. The across-quintet voice alternation pattern used in Experiment 1 was applied to every quintet of trials, except for the 11th. Whereas the first trial of the 11th quintet consisted of a typical, hence predictable, change of voice (from male to female voice), an unpredictable change of voice (from female to male voice) occurred on the next trial (i.e., at Trial Position 2; see Figure 5). Then the same voice (male voice) accompanied the three remaining trials of Quintet 11. The typical across-quintet voice alternation pattern was then applied from the next quintet (i.e., Quintet 12) until the end of the experiment.

Results

First, we examined whether the basic voice-change effect was replicated. Given the additional change of voice introduced within Quintet 11 in this experiment, this analysis included the data for only Quintets 2–10 (as in Experiment 1, the first quintet was also excluded because there was no voice change until Quintet 2). Figure 6 presents the mean percentage of correctly recalled items in Quintets 2–10 for each trial position. Replicating the results of Experiment 1, serial recall performance was poorer at Trial Position 1 than at subsequent trial positions. This was confirmed by a repeated-measures ANOVA carried out on correct recall, revealing a significant effect of trial position, $F(4, 92) = 6.96$, $p < .001$, $d = 1.10$, and a combination of significant linear, $F(1, 23) = 15.36$, $p = .001$, and quadratic, $F(1, 23) = 14.47$, $p = .001$, trends. Multiple comparison tests showed that recall at Trial Position 1 was significantly poorer than at any other trial position ($ps < .001$). Recall performance was comparable across Trial Positions 2–5 ($F < 1$), but there was no significant linear trend when Trial Position 1 was omitted from the analysis (slope = –0.28%, $F < 1$), suggesting that the impact of the across-sequence change of voice was confined to the trial in which the voice change occurred.

Second, we again examined whether the first encounter with the irrelevant sound captured attention by examining recall performance across the first two quintets of trials (see Figure 7). As in Experiment 1, it is clearly evident that, whereas performance was relatively stable across the first quintet of trials, recall was disrupted markedly on the first trial of the second quintet, after which recall performance recovered for the remaining trials of that quintet. This pattern was confirmed by a 2 × 5 repeated-measures ANOVA with the factors quintet (first vs. second) and trial position (1–5). Whereas the main effect of quintet was not significant ($F < 1$, $d = 0.04$), that of trial position was significant, $F(4, 92) = 2.74$, $p = .033$, $d = 0.69$. More important, there was a significant interaction between the two factors, $F(4, 92) = 4.20$, $p = .004$, $d = 0.86$. The decomposition of the two-way interaction revealed that the effect of trial position was significant for the second quintet, $F(4, 92) = 6.10$, $p < .001$, $d = 1.03$, but not for the first[2] ($F < 1$, $d < 0.36$) and that the only difference in performance between the two quintets was observed at Trial Position 1, $t(23) = 3.45$, $p = .002$, $d = 1.44$.

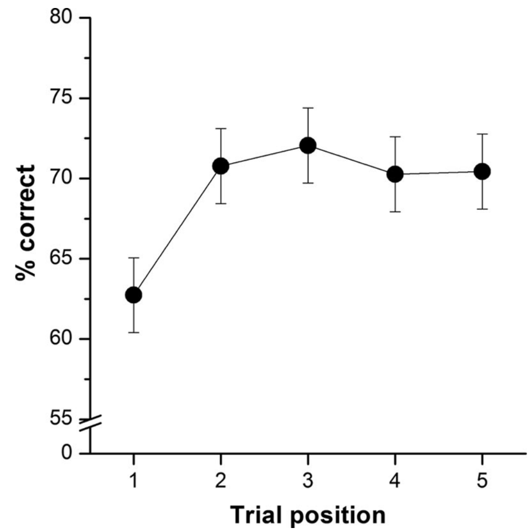

Figure 6. Results from Experiment 2: Mean percentage of items correctly recalled for each trial position (1–5) for the second to the 10th quintet of trials. Error bars represent 95% within-subject confidence intervals.

Third, to examine any across-session habituation of the capture effect, we compared performance at Trial Position 1 with performance pooled across Trial Positions 2–5 for quintets involving a change of voice at Trial Position 1 (thus the first quintet was not included). On this occasion, the last four quintets (Quintets 11–14) were also excluded from this analysis because of the atypical voice change occurring in Quintet 11 in this experiment. The results are presented in Figure 8. The profiles for Trial Position 1 and Trial Positions 2–5 were contrasted across the nine quintets of interest using a profile analysis. With Wilks's criterion, the significant level test indi-

[2] As in Experiment 1, we examined whether an attention-capture effect in the first trial of the experiment went unnoticed due to collapsing recall performance across serial positions. Again, the analysis of performance at the first serial position revealed a pattern similar to that observed when all serial positions were considered: There was no effect of trial position in the first quintet, $F(4, 92) < 1$, $d = 0.27$, but there was indeed a significant effect in the second quintet, $F(4, 92) = 2.43$, $p = .053$, $d = 0.65$, providing further evidence for the absence of attentional capture in the first trial of the experiment.

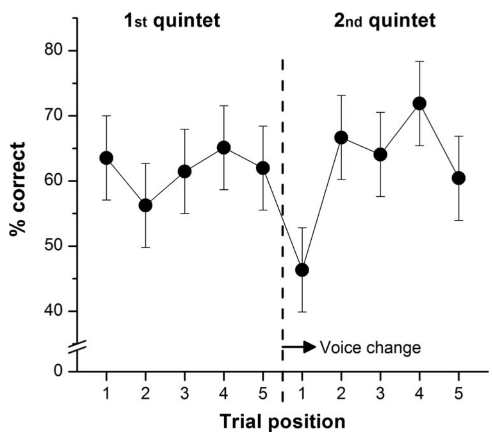

Figure 7. Results from Experiment 2: Mean percentage of items correctly recalled in each of the first two quintets of trials. The items that composed the irrelevant auditory sequence accompanying the to-be-remembered sequence were conveyed in a female voice for the first quintet and in a male voice for the second quintet so that a change of voice occurred at Trial Position 1 of the second quintet (illustrated by the dashed bar). Error bars represent 95% within-subject confidence intervals.

cated that recall was poorer overall at Trial Position 1 (Λ = .429), $F(1, 23) = 30.62$, $p < .001$, whereas the significant flatness test pointed to a general practice effect (Λ = .402), $F(8, 16) = 2.98$, $p = .030$. More important, the parallelism test was significant (Λ = .202), $F(8, 16) = 7.89$, $p < .001$, suggesting that, as we found in Experiment 1, the detrimental impact of the voice change declined as the voice change became progressively more predictable. Also as in Experiment 1, the attention-capturing power of the voice change appeared to be restricted to the first few encounters because the parallelism test was no longer significant when excluding Quintets 2–4 (Λ = .787, $F <$ 1). The results of a 2 × 9 repeated-measures ANOVA performed on correct recall with trial position (1 vs. 2–5) and quintet (2–9) were consistent with those of the profile analysis.

Fourth, we turn to examine the key, novel question that Experiment 2 was designed primarily to address, namely, whether the presentation of an unpredictable change of voice in the second trial of Quintet 11 captured attention. To do so, we contrasted recall in each trial position of Quintet 11 with that during the few preceding quintets (Quintets 9 and 10) as well as the subsequent quintets (Quintets 12–14). Figure 9 shows that performance remained relatively stable across trial positions and quintets, except at Trial Positions 2 and 3 of Quintet 11, where recall is clearly poorer. This was confirmed by a 5 × 5 repeated-measures ANOVA carried out on correct recall with quintet (9–14) and trial position (1–5) as within-subject factors. The main effect of trial position was significant, $F(4, 92) = 2.94$, $p = .025$, $d = 0.72$, whereas that of quintet was not, $F(5, 115) = 1.12$, $p = .356$, $d = 0.44$. Most important, the interaction between quintet and trial position was significant, $F(20, 460) = 1.84$, $p = .015$, $d = 0.57$. This two-way interaction arose because the effect of trial position was significant for Quintet 11, $F(4, 92) = 6.79$, $p < .001$, $d = 1.09$, but not for the other four quintets (Fs < 1). Comparisons of performance across the five trial positions of Quintet 11 revealed that recall at Trial Positions 2 and 3 was significantly poorer than at the other trial positions (ps $< .01$).

Discussion

Experiment 2 replicated the main findings from Experiment 1 and also provided further evidence to support the expectancy-violation account over the novelty-detection account: The across-sequence voice change captured attention as indexed by its disruption of serial recall at Trial Position 1. Again, no capture effect was observed on the first encounter with the irrelevant auditory material (see Figure 7), contrary to a prediction of the novelty-detection account but in line with the expectancy-violation account. As in Experiment 1, the power of the voice change to attract attention habituated after only a few such changes as the voice change became increasingly expectable, as predicted by the

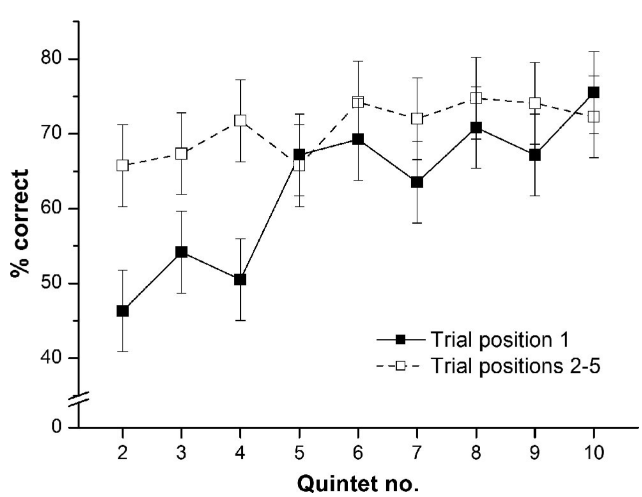

Figure 8. Results from Experiment 2: Mean percentage of items correctly recalled at Trial Position 1 and Trial Positions 2–5 (i.e., performance collapsed across Trial Positions 2–5) in Quintets 2–10. Error bars represent 95% within-subject confidence intervals.

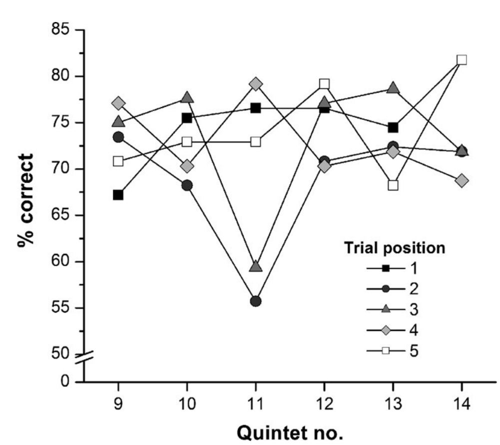

Figure 9. Results from Experiment 2: Mean percentage of items correctly recalled in each of the last six quintets of trials (i.e., Quintet 9–14) as a function of trial position. An unpredictable change of voice occurred at Trial Position 2 of the 11th quintet.

expectancy-violation account (see Figure 8). Although this latter observation can also be accommodated by the novelty-detection account, this account cannot readily explain the novel finding from Experiment 2, namely, the capture effect following a change of voice that occurred "unexpectedly" within a quintet of trials relatively late into the experimental session (see Figure 9). To elaborate, the novelty-detection account of attentional capture could explain the across-session habituation of the attentional response by assuming that the multiple encounters with the two voices rendered them less and less novel as the experiment progressed. Thus, on this account, the female voice encountered at Trial Position 1 of Quintet 11 (see Figure 5), for example, did not capture attention, because by this time in the session, a well-specified neuronal model of the female voice would have been formed. However, by the same logic, it follows that, contrary to the results, the male voice encountered at Trial Position 2 should not have captured attention either, because of the well-specified neuronal model of the male voice.[3] In contrast, the capture effect observed in Quintet 11 is explicitly predicted by the expectancy-violation account: The voice change that occurred at Trial Position 2 captured attention because it broke the expectation based on the rule "the voice conveying the irrelevant stimuli changes (only) every five trials" extracted over the course of the session up to that point. This result confirms that the cognitive system is not only capable of extracting regularities within relatively quickly presented trains of sound but can also extract ones that traverse quintets of sequences of sound that are spaced relatively wide apart.

The disruption of serial recall found at Trial Position 3 of Quintet 11 (see Figure 9)—that is, on the trial immediately following the "unpredictable" voice change—is rather intriguing because it was predicted by neither the novelty-detection account nor the expectancy-violation account, at least not explicitly. It is particularly difficult for the novelty-detection account to accommodate this finding, however, because the auditory stimulation would match the neuronal model of the male voice formed during the preceding trial. On the expectancy-violation account, there are at least two possible explanations: One is that by Trial Position 3 of Quintet 11, a relatively local-level rule-based neuronal model was already formed of the alternating voice pattern evident across Trials 50–52 (cf. Figure 5), a rule that was violated on Trial 53 (see, e.g., Bendixen et al., 2007; Horváth et al., 2001). A second possibility is that the original across-quintet rule was resilient to the single anomaly in the pattern on Trial 52 (hearing a male voice when a female voice was expected) and hence that the original neuronal model was reinstated before the initiation of Trial 52, and this would again lead to the expectation for a female sequence on Trial 53 when a male sequence was in fact encountered.

At first glance, a third plausible account of the disruption of serial recall on Trial 53 is that it simply reflected a general difficulty in refocusing on the task in hand following the disruption of performance on the previous trial (Trial Position 2). Such "postdeviant" effects are not new, because the presence of distraction in the first "standard" trial following a deviant trial has been reported on numerous occasions in the context of both unimodal (see, e.g., Roeber, Widmann, & Schröger, 2003) and cross-modal (Parmentier & Andrés, 2010) oddball tasks. Typically, these studies showed longer response times in deviant trials as well as in the subsequent standard trial relative to the remaining standard trials. One common view is that postdeviant distraction is not a consequence of attentional capture but rather reflects the cost of completing the reactivation of the task set for the next (standard) trial (see, e.g., Parmentier & Andrés, 2010). However, although plausible within the context of the oddball task, this account does not seem as well suited to the present findings. Usually, in the cross-modal oddball task (see, e.g., Escera et al., 1998; Parmentier, 2008; Parmentier & Andrés, 2010), the stimulus presentation and the response window are rather short (e.g., 1,100 ms in Parmentier, 2008), and the next trial is automatically initiated after the end of the response window. With such a fast pace, the impact of task-set reactivation on postdeviant trials is conceivable. However, given the slow pace of our serial recall task, such task-set reactivation is likely to have been completed before the end of the to-be-remembered list of the deviant trial—the list was presented for 4,450 ms—and, consequently, is unlikely to have affected recall on the next (postdeviant) trial. Even if the task-set reactivation hypothesis were to be considered plausible in the current experimental context, it would in any case fail to account for the absence of postdeviant distraction on postdeviant trials of the first few quintets of the experiment (i.e., at Trial Position 2). Although further work is required to fully address this particular issue, this is beyond the scope of the present study; the important point as far as our key hypothesis is concerned is that attention was captured by a break in the experiment-wide voice-alternation rule.

General Discussion

The present study established that attentional capture is produced when an irrelevant auditory sequence presented concurrently with a visually presented focal task changes from a female-spoken sequence to a male-spoken sequence (and vice versa) as indexed by a recovery of performance with continued exposure to the same voice over a further few trials. Critically, the detailed pattern of findings suggests strongly that the underpinning mechanism for this behavioral distraction was expectancy violation, not novelty detection. First, there was no evidence of attentional capture when the irrelevant material was first encountered and hence was entirely novel to the participants: Performance remained stable across the first five trials in both experiments. Rather, only when the irrelevant sequence changed such that it violated an expectancy was attentional capture elicited. This finding indicates that novelty was not sufficient; an expectancy violation was necessary. Second, with the increasing predictability (and hence expectancy) of the change of voice—that is, every sixth trial—the across-sequence deviation effect waned over the course of the experiment. That this habituation of the attentional response was based on the development of a rule-based neuronal model was demonstrated by the fact that a deviation from the overall, high-order pattern of auditory sequences—in the absence of new (i.e., novel) stimulation—reinstated the capture response (Experiment

[3] Note that the novelty-detection account cannot escape this predicament by supposing that exposure to the female voice on Trial Position 1 of Quintet 11 "wiped out" the neuronal model of the male voice, thereby allowing it to explain, after all, the attentional capture by the change to a male voice at Trial Position 2. If this were the case, the novelty account would have no means of explaining the across-session habituation effect in the first place.

2). This second key observation indicates that novelty was not necessary; expectancy violation was sufficient.

Novelty Not Sufficient, Expectancy Violation Necessary?

The absence of attentional capture by the irrelevant sequence within the first quintet of trials (and especially on the very first trial) is at odds with the novelty-detection account of auditory distraction based on the poor-or-lack-of-neuronal-model mechanism. The novelty-detection account assumes that the OR triggered by the first stimulus (see, e.g., O'Gorman, 1979) and that triggered by a stimulus change (see, e.g., Näätänen & Gaillard, 1983) are initiated by the same brain processes because in both cases a neuronal model of the eliciting stimulus is lacking. However, there is evidence that they may be functionally distinct (see, e.g., Näätänen, 1986, 1990; Näätänen & Picton, 1987; O'Gorman, 1979; Sokolov et al., 2002). For example, the distinction is supported by the dissociation of two auditory ERP components: the N1 and the MMN. The N1 wave is especially large for the first stimulus after a relatively long silent period and quickly attenuates in amplitude with stimulus repetition (for a review, see Näätänen & Picton, 1987). This N1 enhancement is thought to reflect the initial OR because it is activated only by the first stimulus and is generally elicited by a sudden energy increase (i.e., transient) after sensory quiescence (see, e.g., Näätänen, 1986; Näätänen & Gaillard, 1983). Hence, the initial OR, as indexed by the N1, appears to be more sensitive to energy onset of any stimulus (i.e., to stimulus occurrence) than to novelty per se (see, e.g., Näätänen, 1986, 1990). For example, the N1 has a similar amplitude for standards and deviants when sounds are separated by a relatively long interstimulus interval such as 1–2 s (Näätänen & Picton, 1987). So, given the long time interval (15 s) between two consecutive sequences in the current experiments, it may be that the OR elicited by the first sound of every auditory sequence was similar in magnitude for voice-change and voice-repetition sequences. Thus, the initial OR seems to be associated with the mere detection of stimuli and not with the detection of novelty or change. This is entirely consistent with the absence of an effect on the first quintet found in our experiments.

The pattern of data across the first two quintets of trials is more in line with expectancy violation as the key mechanism underlying behavioral distraction by auditory attentional capture. Expectancy-violation detection has been associated with the MMN, a necessary precursor to behavioral attentional capture by that change[4] (or the change OR; see, e.g., Näätänen, 1986, 1990; Schröger, 1997; Winkler, 2007). More specifically, the MMN is elicited by sounds violating some repetitive as well as nonrepetitive regularities extracted from previous intersound relationships, suggesting that the mechanism responsible for its generation relies on a well-structured representation of the auditory scene (Winkler, 2007). Hence, in line with the present results, the "MMN is not elicited by isolated sounds or a sound change occurring in the beginning of a sequence" (Winkler et al., 2009, p. 535). However, the MMN is typically associated with a single, rule-deviant sound embedded within a continuous train of sounds, whereas in the present study the change occurred across relatively temporally discrete sequences of sounds. There is evidence that the MMN is not elicited by a deviant sound presented at the beginning of a sequence when the intersequence interval is larger than 11 s (see, e.g., Cowan, Winkler, Teder, & Näätänen, 1993; Winkler, Schröger, & Cowan, 2001). Accordingly, it would be interesting to examine whether an MMN can be found for the first stimulus of a series in the context of an across-sequence deviation. Such an electrophysiological investigation could allow the pinpointing of the exact moment at which the across-sequence expectancy violation is detected.

Novelty Not Necessary, Expectancy Violation Sufficient?

In addition to the demonstration that attention was not captured by the irrelevant sequences during the first quintet of trials, the second key finding from the present study is the habituation of the attentional response to the predictable across-sequence voice change and its reinstatement (or dishabituation) through an unexpected break in the across-quintet voice-alternation pattern. Although this finding is problematic for the novelty-detection account (see Discussion of Experiment 2), it is readily explained in terms of the formation of a predictive regularity representation (cf. Winkler et al., 2009) of the broad structure of the irrelevant sound sequences. Indeed, the present results suggest that the neuronal model can embody acoustic regularities that encompass several task-irrelevant sequences of sounds and allow predictions about the auditory scene from such a suprasequence pattern. The fact that habituation to the across-sequence voice-alternation pattern manifested around the fifth quintet of trials—that is, after hearing about 20 sequences of 10 sounds each—suggests that representations of suprastimulus (or suprasequence) invariance is not confined to the short term (see, e.g., Cowan et al., 1993; Winkler & Cowan, 2005).

It has been suggested that rule extraction from auditory sequences derives from the primary function of perceptual streaming whereby the auditory system determines whether successive sounds share the same source on the basis of gestalt-like principles such as similarity and good continuation (*sequential integration*; Bregman, 1990; see, e.g., Hughes et al., 2007; Kubovy & Van Valkenburg, 2001; Mondor, Zatorre, & Terrio, 1998; Winkler et al., 2009). In line with the current evidence for long-term rule extraction from irrelevant sound, there is evidence that sequential integration can operate across widely temporally separated sounds without attention (see, e.g., Anstis & Saida, 1985; Winkler et al., 2001). Hence, it is possible that such large-scale organization occurred in the present context so that each irrelevant sequence and subsequently each quintet of sequences was perceived as a single auditory object, leading to the detection of the (across-quintet) voice-alternation pattern, in turn leading to the reduction of the attention-capture power of the voice change.

Converging Support for the Expectancy-Violation Account

That expectancy violation plays the key role in behavioral auditory attentional capture gains further support from two further

[4] It is noteworthy that the MMN is not considered to be an index of attention capture by deviant stimuli. Rather, the MMN is viewed as a *call for attention* (see, e.g., Näätänen, 1990; Öhman, 1979), which, when answered, is followed by a P3a, an ERP component that reflects processes that are involved in an involuntary attention switch (see, e.g., Escera et al., 2000).

recent strands of evidence (Hughes, Vachon, & Jones, 2005, 2007; Parmentier et al., 2011). The first is the dissociation of the deviation effect from the so-called *changing-state effect* in serial recall (Hughes, Vachon, & Jones, 2005, 2007). The changing-state effect refers to the fact that a sequence of irrelevant changing sounds (e.g., FBRTL . . .) presented during a serial recall list is far more disruptive than a steady-state sound (FFFFF . . .) and has played an important role in short-term memory theory (see, e.g., Hughes, Tremblay, & Jones, 2005; Jones & Macken, 1993; Larsen & Baddeley, 2003; Neath, 2000; Page & Norris, 2003). One popular view of the changing-state effect is that it is underpinned by the same attentional capture mechanism that is elicited by deviant sounds (see, e.g., Bell, Dentale, Buchner, & Mayr, 2010; Bell, Mund, & Buchner, 2011; Chein & Fiez, 2010; Cowan, 1995, 2005; Elliott, 2002; see also Neath, 2000). On this view, each element in a changing-state sequence acts as a novel and hence capture-eliciting event, drawing scarce attentional resources away from the focal recall task, whereas the capture response quickly habituates with a steady-state sound. However, problematic for this view is that there is a double dissociation between the effects of a deviant and those of a changing-state sequence: The changing-state effect is found when the sound is confined to a retention interval presented between the last to-be-remembered item and a cue to recall, whereas the deviation effect is not (Hughes, Vachon, & Jones, 2005). Conversely, the deviation effect is found during the encoding phase of short-term memory tasks regardless of whether the task calls for serial coding (or rehearsal), whereas the changing-state effect is found only in the context of serial rehearsal-based tasks (Hughes et al., 2007; Jones & Macken, 1993). In the same vein, Sörqvist (2010) found that working memory capacity correlates negatively with vulnerability to the deviation effect but not with the changing-state effect. Finally, the fact that in the present study the impact of deviations habituated over the experimental session constitutes a yet further dissociation from the changing-state effect, which remains relatively stable across a session (Hughes, Vachon, & Jones, 2005; Jones, Macken, & Mosdell, 1997). Although Hughes, Vachon, and Jones (2005) reported that the impact of a single voice deviant did not diminish over time, this was in the context of a design in which, unlike in the present study, the occurrence of deviants did not become predictable. We have argued, therefore, that the changing-state effect is not driven by attentional capture but is a form of interference-by-process whereby the obligatory order encoding of changing-state sound conflicts with the similar seriation process underpinning serial recall (see, e.g., Hughes et al., 2007). That the changing-state effect is not readily attributable to attentional capture again suggests that behavioral capture effects are not driven by novelty detection. Moreover, supporting the view that expectancy violation is the key mechanism, the repetition of an event following regularly alternating (and hence changing) events (cf. Nordby et al., 1988) within an irrelevant speech sequence also disrupts serial recall (Hughes et al., 2007, Experiment 3).

A second strand of evidence that lends support to our emphasis on expectancy violation over novelty detection comes from a recent study of speeded reactions in the cross-modal oddball task (Parmentier et al., 2011). In this task, participants are required to classify a visually presented digit (e.g., as odd or even) each of which is accompanied by a task-irrelevant sound (Escera et al., 1998; Parmentier, 2008; Parmentier et al., 2008; Parmentier, Elsley, & Ljungberg, 2010). The attentional capture effect in this paradigm is indexed by a slowing of reaction time when the digit is accompanied by a rarely presented novel sound (e.g., a noise burst on 25% of trials) that differs from the remaining (standard) sounds (e.g., a tone presented on 75% of trials). In a design in which the noise bursts came, for the most part, in pairs (i.e., a noise burst on two consecutive trials), Parmentier et al. (2011) found that the second instance of the noise burst failed to capture attention. Conversely, a standard sound presented following a rare occasion on which a noise burst was presented in isolation did indeed capture attention. The conclusions clearly converge strongly with ours: The second novel in a pair failed to capture attention because, despite being relatively novel, it did not violate expectations, whereas a standard following a single noise burst, despite being relatively unnovel, captured attention because it did indeed violate expectations. That expectancy violation, not novelty, has been shown to be the key factor in behavioral auditory attentional capture using reaction times (Parmentier et al., 2011) as well as memory errors (present study) and with a simple binomial categorization task (Parmentier et al., 2011) as well as a demanding serial recall task (present study) suggests that our theoretical conclusions have a good degree of generality.

Potential Challenges

One possible challenge to our emphasis on expectancy violation over novelty detection could be based on studies that have found that allowing participants to listen passively to auditory stimuli before those stimuli are then used as distractors during a focal task diminishes their disruptive effect (Banbury & Berry, 1997; Elliott & Cowan, 2001; Waters et al., 1977; but see Jones et al., 1997). For example, Waters et al. (1977) used a task in which arithmetic problems were presented in a male voice concurrently with irrelevant two-digit numbers and arithmetic symbols presented in a female voice. Those participants who had been preexposed to the irrelevant material performed better on the first few arithmetic problem trials than did participants who had been preexposed to only a tone or had not been preexposed to any auditory material. On the face of it, such findings seem most readily explained in terms of a novelty-detection account: Preexposure to the to-be-distractors allows for a neuronal model of those distractors to be developed, hence stripping them of their attention-capturing power when subsequently presented during the selective attention task. Arguably, it is less plausible to assume that such preexposure would lead to a (violable) expectation that those stimuli would be presented as distractors in a later task.

However, on closer inspection, the implications of studies that have used the preexposure method are far from straightforward. For example, it is not clear that the disruption found in those studies was due to attentional capture: Two of the three studies that have found preexposure effects involved a setting in which either the irrelevant stimuli provided information closely related to the responses required in the focal task (Waters et al., 1977) or there was at least a relatively high probability of the irrelevant stimuli being response-relevant (Elliott & Cowan, 2001). Hence the disruption may instead be due to response interference or be related to an expectation for such interference. If so, preexposure may reduce later distractor potency by promoting the use of an active inhibitory process designed to reduce response interference (see, e.g., Tipper, 2001) rather than allow passive habituation of attentional orienting through the fabrication of a neuronal model. Indeed, when the auditory material is never response-relevant, the evidence for preexposure effects is both sparse and mixed: Whereas Banbury and Berry (1997) found a beneficial effect of preexposure in the context of the disruption of memory for prose in the presence of background office noise, Jones et al. (1997) failed to replicate such an effect in the context of disruption of serial recall by irrelevant speech (compared with a quiet control condition). Thus, data from preexposure studies are at present inconclusive in terms of whether they discriminate between novelty-detection-based and expectancy-violation-based accounts of auditory attentional capture.

A second potential challenge comes from studies using the cross-modal oddball task (described earlier in the context of the implications of the study of Parmentier et al., 2011) that have obtained qualitatively different effects (in terms of both ERP and behavioral indices) for what have sometimes been labeled "slightly deviant" and "novel" sounds. For example, using a tone as a standard (i.e., frequent) sound, Escera et al. (1998) found that the presentation of an experimentally unique sound (e.g., a single instance of the sound of a drill) produced a different outcome in terms of ERP and behavioral indices of attentional capture from that of a tone that was slightly different in frequency from the standard. They argued on this basis that there were two distinct mechanisms responsible for attentional capture: one based on stimulus novelty and one based on stimulus deviance (see also Escera, Alho, Schröger, & Winkler, 2000). However, although Escera et al.'s (1998) findings show an empirical dissociation, whether this dissociation necessarily indicates two qualitatively different mechanisms in this case is less clear. The novel stimuli in their study were also highly deviant. Indeed, Escera et al. (1998) themselves describe their deviants and novels as, respectively, "slightly deviant" and "widely deviant" (p. 590). It seems possible, therefore, that the qualitatively different outcomes may have been the result of a large quantitative difference in the degree to which the slightly deviant and widely deviant sounds violated expectancies (rather than the different effects resulting from two qualitatively distinct mechanisms). Indeed, in discussing the impact of entirely novel (i.e., unique within the experimental context) *environmental sounds*, Sokolov et al. (2002, p. 141) suggested that the large amplitude of the P3a response (a neural index of attentional switching) found for such sounds "might be in part explained by a strong MMN process elicited by such a novel sound. (In general, the P3a amplitude is larger for larger magnitudes of stimulus deviation; see Näätänen, 1992)." Moreover, the slightly deviant sounds in Escera et al. (1998) were also relatively novel; they comprised 10% of the sounds heard across the experiment. Thus, the different outcomes for slightly deviant and novel sounds may have arisen because of either a large difference on the dimension of deviance or a large difference on the dimension of novelty. The results of Parmentier et al. (2011) discussed earlier using the same paradigm suggest that the former account is the more likely, at least in relation to behavioral capture effects.

Summary and Conclusions

Cognitive–behavioral research on auditory attentional capture—embedded in information processing theories of selective attention—has tended, to date, to gloss over the distinction between novelty detection and expectancy violation (see, e.g., Cowan, 1995; Dalton & Lavie, 2004; Elliott & Cowan, 2001; Lange, 2005; Parmentier et al., 2008; Waters et al., 1977). Indeed, the two types of neuronal-model mechanisms—that of a poor or lack of neuronal model and that of a violation of a neuronal model—have sometimes been discussed interchangeably in this literature (see, e.g., Cowan, 1995). The present study as well as the recent study by Parmentier et al. (2011) highlight the fact that the former mechanism is inadequate to explain the full pattern of behavioral attentional capture effects: Although the poor-or-lack-of-neuronal-model mechanism can explain attentional capture by a novel stimulus, it cannot explain attentional capture by a stimulus that is relatively unnovel but violates expectancies or cases in which there is no capture despite novelty. The violation of a neuronal model mechanism can account parsimoniously for both these cases. More important, it does not appear that a mechanism for detecting novelty per se is required at all in cognitive theory: When a stimulus is novel but does not violate expectancies, it is stripped of its power to disrupt cognitive performance, and a stimulus that is not novel can indeed disrupt ongoing cognition if it violates expectancies (present study; Parmentier et al., 2011). At the very least, our results serve to underline the importance of not conflating the concepts of novelty detection and expectancy violation in the context of cognitive–behavioral distraction by auditory attentional capture.

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