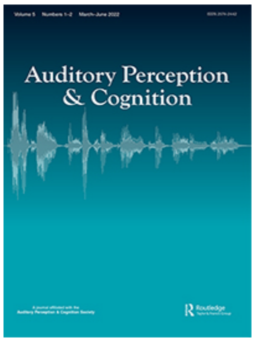

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Acoustic, and Categorical, Deviation Effects are Produced by Different Mechanisms: Evidence from Additivity and Habituation

Zoe Littlefair[a], François Vachon[b], Linden J. Ball[a], Nick Robinson[c] and John E. Marsh[a,d]

[a]School of Psychology and Computer Science, University of Central Lancashire, Preston, UK; [b]School of Psychology, Université Laval, Quebec City, Canada; [c]Nick Robinson Computing Limited, UK; [d]Department of Business Administration, Technology and Social Sciences, Humans and Technology Luleå University of Technology, Sweden

ABSTRACT

Sounds that deviate, acoustically or semantically, from prevailing auditory backgrounds disrupt ongoing mental activity. An acoustic deviant is held to capture attention, but doubt has been cast on the attentional nature of the semantic, categorical deviation effect. Unlike the acoustical deviation effect, which is typically amenable to top-down cognitive control, the categorical deviation effect is impervious to top-down influences.To shed further light on the mechanisms underpinning acoustic and categorical deviance, we compared the disruptive impact produced by acoustic deviants (change of voice), categorical deviants (change of category) and combined deviants (change of voice and category) randomly inserted into a to-be-ignored sequence while participants performed a visual-verbal serial recall task.In Experiment 1, all deviants disrupted recall, however combined deviants produced greater disruption than acoustic deviants alone. In Experiment 2 only the disruption produced by an acoustic deviant diminished over the course of the experiment. The acoustic and categorical deviation effects combined additively to disrupt performance (Experiment 1) and habituation was only observed for the acoustic deviation effect (Experiment 2).These results gel with the idea that attentional responses to deviants, and habituation thereof (Experiment 2), is a key component of acoustic but not categorical deviation effects. Taken together, these findings support recent assertions that independent mechanisms drive acoustic and categorical deviation effects.

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Acoustic deviant; categorical deviant; attentional capture; habituation

Introduction

Sounds that are completely irrelevant to tasks in which we are currently engaged are ubiquitous within our environments. These task-irrelevant sounds are processed despite our best efforts to ignore them. Such obligatory processing of sound is a consequence of

CONTACT John E. Marsh jemarsh@uclan.ac.uk School of Psychology and Computer Science, University of Central Lancashire, UK

the inherent "openness" of the auditory system: While we can close our eyelids or focus our visual attention elsewhere to avoid seeing, there is no comparable means to prevent us hearing – our sense of hearing is always on. Furthermore, our selective attentional systems are not impermeable. That is, they do not completely gate-out the processing of sound. In fact, an impenetrable selective attention system would be maladaptive, since there is a simultaneous need to remain open to unexpected changes, or deviations, in task-irrelevant information should they signal events that require action (Allport, 1993; Hughes & Jones, 2003; Johnston & Strayer, 2001). However, set against this indispensable advantage of possessing an "open" sensory-hearing system, and a permeable selective attentional system, is the unwelcome consequence of distraction. Sudden changes within the environment that have no relevance for the organism are capable of wresting attention from focal task activity thereby interrupting, and typically impairing, focal task performance (Hughes et al., 2005, 2007, 2013; Vachon et al., 2012; Marsh et al., 2014, p. 2015). Much research has focused on the usually disruptive impact that unexpected acoustic irregularities (deviants) have on the performance of a concurrent task (Hughes et al., 2007; Parmentier, 2014, 2016; Vachon et al., 2017).

Recent research (Vachon et al., 2020) demonstrates that a categorical change within the content of a task-irrelevant auditory sequence (e.g., a letter among digits), in the absence of an acoustic irregularity (e.g., all items presented within the same voice), also disrupts performance. Vachon et al. (2020) propose that the mechanism of distraction underpinning this categorical deviation effect differs from the attentional capture mechanism of distraction widely held to underpin the acoustic deviation effect. In the current study we further explore this claim by first investigating whether acoustic and categorical deviants are additive in their disruptive effects on task performance, as might be expected if they are subtended by different mechanisms (Experiments 1 and 2) and second, through addressing the extent to which habituation of the orienting response to, and thus diminution of the disruptive behavioral effects of, acoustic deviants, categorical deviants and combined (acoustic and categorical) deviants occur over the course of an experimental session (Experiment 2).

Much of what has been gleaned about the impact of task-irrelevant sound on cognitive processing has been learned from the irrelevant sound paradigm (Colle & Welsh, 1976; Jones et al., 1992; Miles et al., 1991; Salamé & Baddeley, 1982). This paradigm includes a behavioral task (serial recall) that is sensitive to the disruptive effects of background sounds. Participants are presented (usually visually) with a list of 6 −9 to-be-recalled items (e.g., letters or digits) that they are required to reproduce in their order of presentation. The presence of a rare, unexpected change in a sequence of task-irrelevant sounds appreciably impairs serial recall performance compared to a quiet control condition (Hughes et al., 2005, 2007; Lange, 2005; Röer et al., 2011). Such an unexpected change could involve one letter presented in a different frequency or voice (voice "B") from the remainder (in voice "A"): "AAAABAA … " or a change in the inter-stimulus interval between to-be-ignored items (Hughes et al., 2005, 2007; Sörqvist, 2010; Vachon et al., 2012). Since evidence for this deviation effect has emerged primarily from pre-categorical, acoustic changes, it has been referred to as the *acoustic deviation effect* (Vachon et al., 2020).

There is broad agreement that this acoustic deviation effect is caused by a diversion of attention away from the focal mental activity toward the sound triggered by the incoming deviant item (Bell et al., 2019; Cowan, 1995; Hughes et al., 2005, 2007; Schröger, 1997; see also, Lange, 2005; Marois & Vachon, 2018; Marois et al., 2019; Marsh et al., 2014; Muller-Gass et al., 2007; Parmentier, 2008; Sörqvist, 2010; Vachon et al., 2017). A widely accepted assumption is that a deviant item produces attentional capture because its acoustic features violate the forward (predictive) model that generates expectations of an impending stimulus, or those of an immediately preceding experience (Bendixen et al., 2007; Hughes et al., 2005, 2007; Marois et al., 2020; Parmentier et al., 2011; Sokolov, 1963; Vachon et al., 2012; Winkler et al., 2009). The involuntary switch of attentional focus to the deviant item (or attentional capture mechanism) is assumed to reflect a covert component of the orienting response (Näätänen, 1992). Observable at physiological, behavioral and cognitive levels (Lynn, 1966), the orienting response is taken to index the detection of – and involuntary switching of attention toward – a stimulus that deviates from a preceding pattern of sensory stimulation.

The finding that acoustic deviants (e.g., inter-stimulus intervals, pitch/voice) produce an orienting response (and attentional capture; Hughes et al., 2005, 2007; Vachon et al., 2012), suggests that the pre-attentively fabricated mental description of incoming auditory stimuli (predictive model, or neural model) against which subsequent auditory stimuli are compared, represents acoustic features of the auditory input. However, recent evidence suggests that the predictive model may also represent post-categorical features: If auditory items from an otherwise homogeneous set of category-items are interrupted by a token from a different category, serial recall performance is also impaired (Vachon et al., 2020). Further, the post-categorical representation of features occurs for semantically rich material, since disruption ensues for sequences in which there is an insertion of a single category-exemplar into a sequence of words belonging to a different category such as "dog, cat, cow, horse, knee, sheep," as well as for streams containing a single insertion of a letter among digits "FTLV2XQ," or vice versa.

Although similar in behavioral outcome to the acoustic deviation effect, the disruption to serial recall produced by a categorical deviation effect cannot be attributed to acoustic change: When acoustical and phonological similarities between the categorical deviants and non-deviants were computed, they were shown not to differ (see, Vachon et al., 2020, Table B2). Further, there is nothing inherent in the content of categorical deviants that should give them the power to capture attention: They have no personal significance, or motivational value that would trigger an attentional response unlike, for example, one's own name (Moray, 1959; Röer et al., 2017). Therefore, any explanation that the acoustic deviation effect is masquerading as a categorical deviation effect is lacking. Further, the evidence suggests that contextual changes in the content of the task-irrelevant sequence, rather than the meaningfulness of the deviant stimulus, produces disruption (Vachon et al., 2020). If post-categorical content is represented within the predictive model of the task-irrelevant sequence to the extent that contextual changes in semantic content are detected, then it is possible that such an irregularity, like an acoustic irregularity, will trigger an orienting response or attentional capture mechanism. On this view, the categorical deviation effect could represent the action of a sentinel system, similar to the one responsible for the orienting response to acoustic deviations, but which would record the semantic properties of auditory stimulation instead of its acoustic properties

(Vachon et al., 2020). This theorizing suggests that the same, or similar, attentional capture account (Hughes et al., 2013, 2005, 2007; Vachon et al., 2012) could underpin both acoustic and categorical deviation effects.

A growing body of empirical findings, however, undermines an attentional capture account of the categorical deviant effect (Vachon et al., 2020). The basis of such works rests on the foundation that the acoustic deviation effect is amenable to manipulations of top-down control (Hughes et al., 2013; see also, Hughes & Marsh, 2020; Marsh et al., 2020) and directly tests whether the same is true of the categorical deviation effect. For example, the promotion of focal-task engagement by increasing the difficulty of identifying the to-be-remembered items (digits), through perceptual degradation (Hughes et al., 2013; see also Parmentier et al., 2008) eliminates the disruption produced by a single letter spoken in a different voice (e.g., female) to other letters (male) in a sound sequence (Hughes et al., 2013; see also, Hughes & Marsh, 2020; Marsh et al., 2020; but see, Kattner & Bruce, 2022). Such shielding of performance from disruption via attentional capture, however, has not been observed in the case of categorical deviants (Vachon et al., 2020). This suggests that a top-down modulation of the allocation of selective attention in response to degraded task conditions – that causes an acoustic deviant to lose its typical power to disengage attention from the serial recall task (Hughes et al., 2013) – is inconsequential for the disruption produced by a categorical deviant. Such a result gels better with the notion that the categorical deviant exerts its disruptive effect via a mechanism other than attentional capture. Labonté et al. (2022) measured participants' working memory capacity with a battery of working memory capacity tests (operation span, symmetry span and rotation span) and directly compared the disruption produced to serial recall performance by categorical deviants and acoustic deviants. Their results replicated the previously reported significant negative correlation between the magnitude of the acoustic deviation effect and working memory capacity (as measured with operation span; Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010; but see, Körner et al., 2017). However, no relationship was found between the categorical deviation effect and working memory capacity. Since high working memory capacity reflects trait (i.e., long-term and stable) capacity for increased, or more steadfast, focal-task engagement that should shield performance from attentional capture by a deviant, its ineffectiveness at modulating the categorical deviation effect further underscores the possibility that it is produced via a mechanism other than attentional capture.

A further finding at odds with an attentional capture account of the categorical deviation effect is its resistance to attenuation via the presence of foreknowledge (Vachon et al., 2020). Hughes et al. (2013) demonstrated that removing the unexpectedness of an acoustic deviant by forewarning participants, on a trial-by-trial basis, of the impending presentation of a deviant, attenuated its disruptive effect on serial recall performance (see also, Horváth & Bendixen, 2012; Sussman et al., 2003). They suggested that the foreknowledge allowed the active incorporation of the deviant into the predictive model of the upcoming sound sequence (Vachon et al., 2012), which would render the physical violation no longer a cognitive one (Hughes et al., 2013). Since such foreknowledge should also allow the categorical deviant to be incorporated into the predictive model for the forthcoming sound sequence, its failure to attenuate the categorical deviation effect (Vachon et al., 2020) further suggests that the categorical against acoustic deviation effect is underpinned by a mechanism that is different from attentional capture.

The foregoing literature review suggests that the disruptive impact of acoustic deviations and categorical deviations may be underpinned by separate mechanisms. Although attentional capture appears a perfectly adequate explanation of the acoustic deviation effect (Bell et al., 2019; Hughes et al., 2013, 2005, 2007), it is a poor explanation of the categorical deviation effect (Labonté et al., 2022; Vachon et al., 2020). The purpose of the current study was to evaluate further whether the acoustic and categorical deviation effects are subtended by different mechanisms. To foreshadow the experimental series, Experiment 1 explored whether the disruption produced by acoustic and categorical deviants is additive or non-additive using the rationale that additivity would indicate they are underpinned by different mechanisms (cf., Sternberg, 1969). Experiment 2 investigated whether the disruption produced by categorical deviations, like acoustic deviations (Hughes et al., 2007; Lange, 2005; Vachon et al., 2017), diminishes across the course of an experiment. If the categorical deviation effect is not subtended by an attentional capture mechanism, then no habituation should be observed. We also included a combined (acoustic and categorical) deviant condition in Experiment 2 to observe the interplay, if any, between acoustic and categorical deviations as inferred through the disruption to task performance.

Experiment 1

In Experiment 1 our goal was to examine the potential disruptive impact on serial recall performance of a single deviation (acoustic vs. categorical) or a double deviation (acoustic and categorical). Although in this study we investigate the additivity versus interactivity of acoustic and semantic irregularities on behavioral performance, it is useful to highlight evidence for their independent processing in the context of electro-psychophysiological investigations. Different electrophysiological markers are associated with acoustically and semantically incongruous events. Acoustical deviations, such as an infrequent change in voice, have long been known to elicit distinct components of the event-related brain potentials. For example, the mismatch negativity (MNN) is assumed to reflect the detection of an irregularity in the recent acoustical context while the P3a has been interpreted as a neural marker of the attentional response to such deviation (Escera et al., 2000; Escera & Corral, 2007; Näätänen et al., 2007; Wetzel & Schröger, 2014). Semantic incongruence (e.g., when a sentence-final word does not match the preceding semantic context), however, produces an N400 (Kutas & Hillyard, 1980, 1984). Thus, the violation of semantic expectancy demonstrates a different time-course and polarity to the violation of acoustic expectancy.

Previous research demonstrates additive, rather than interactive, effects of acoustic (harmonic) and semantic incongruities on electrophysiological and behavioral responses. For example, Besson et al. (1998) presented participants with opera excerpts that contained congruous or incongruous final words sung in an in-key or out-of-key note. Incongruous words sung in-key elicited an N400, while congruous words sung out-of-key, elicited P300s. Incongruous words sung out-of-key yielded an N400 and a P300. Further, the additivity of N400 and P300 was revealed by demonstrating that the N400 component observed for incongruous words sung in-key (minus congruous words sung in-key) and the P300 elicited by congruous words sung out-of-key (minus congruous words sung in-key) did not differ from that observed in the combined condition – incongruous word sung out-of-key (minus congruous word sung in-key). Thus, detection of acoustic deviants is not affected by the semantics of the sentence, and detection of semantic deviants is unaffected by the acoustics of the sentence even when the same stimulus is both an acoustic and semantic deviant. These results imply that the processing of acoustic and categorical deviants might be strongly independent.

If acoustic and categorical deviations are independently processed, as the evidence from electrophysiological studies suggests, then they should contribute unique components to the disruption of serial recall. Further, if the manifestation of the acoustic and categorical deviant effects is underpinned by different mechanisms then the magnitude of disruption that acoustic and categorical deviations produce to serial recall should be additive (cf., Besson et al., 1998; for the additive factors logic, see, Sternberg, 1969). On the other hand, supposing that attentional orienting underpins both acoustic (e.g., Hughes et al., 2005, 2007) and categorical (e.g., Vachon et al., 2020) deviation effects, then a combination of the two effects should be non-additive; that is, if an orienting response is already triggered by one unexpected dimension of a stimulus then the other unexpected dimension would yield little additional disruption (for a similar rationale, see, Hughes et al., 2007; Marois et al., 2019).

Method

Participants

One hundred and ninety-two participants were recruited via opportunity sampling using online links for Experiment 1. Sixty-four adults (24 females; mean age: 24 years) were recruited for the acoustic deviant condition, 63 adults (42 females; mean age: 25 years) for the categorical deviant condition, and 65 adults (47 females; mean age: 22 years) for the combined (i.e., acoustic and categorical) deviant condition. Participants were recruited through Prolific Academic (www.prolific.co) and received a small honorarium for their participation. Within Prolific Academic, custom pre-screening was used to set pre-screening exclusion criteria which included "Dyslexia, Dyspraxia, ADHD or any other related literacy difficulties," "NHS mental health support," "mild cognitive impairment/dementia," "antidepressants," "mental illness," "daily impact," "autistic spectrum disorder" and "mental health/illness/condition–ongoing." Criteria for eligibility included: self-report of normal or corrected-to-normal vision and no hearing loss or difficulties, being 18–30 years, of UK nationality, born and living in the UK and speaking English as a first language. To increase data quality still further, participants were eligible only if their approval rate was greater than 95% for participation in Prolific Academic studies.

Participants were randomly allocated to one of the three between-participants conditions (acoustic deviant, categorical deviant, combined deviant) via OpenLab. The experiment was approved by the ethics committee of the University of Central Lancashire.

Design

A 2 × 3 mixed design was used wherein the deviant type was a between-participants factor and the presence of deviant was a within-participant factor. The dependent variable was serial recall task performance.

Materials

The experiment was run online and programmed using lab.js. Lab.js is a graphical interface within which Javascript can be used to generate experiments (Henninger et al., 2019). The OpenLab web server (https://open-lab.online/) was used to present the experiment and was accessible through a URL.

Visual To-be Remembered Stimuli

These comprised sequences of eight digits sampled without replacement from the set 1 −9. Digits were sampled in a quasi-random order for each trial with the constraints that successive digits were not adjacent integers (e.g., 1 was not followed with 2 or vice versa) and the first-presented digit was not 1. Each digit was 72-point, in a black Arial font and presented in the center of a white background. Digits were presented for 250 ms each and there was a 500 ms interstimulus interval between digit presentations.

Auditory To-be Ignored Stimuli.

For the headphone check task (see below) three 200 Hz tones were used. For the sequences of to-be ignored stimuli for the serial recall task (see below), the letters B, F, H, K, M, Q, R, X and Z were recorded in a male voice in an approximately even pitch. Each item was edited to be 250 ms in length using Sound Forge (Sony) software. The selected letters are all phonologically dissimilar in English. In trials containing an acoustic deviant, the deviant item was recorded in a female voice. The interstimulus interval was 500 ms as for visual presentation. Therefore, the visual and auditory stimuli were presented synchronously. The categorical deviant items consisted of digits between 1 −9 and these were selected and placed in the letter sequences in the deviant trials with the constraint that the categorical deviant was a unique number for each deviant trial. The sequences in standard and deviant conditions were composed as follows:

Standard Trials (No Deviant Item)

These sequences comprised eight letters randomly selected from the set of nine letters. The letters were presented in a random order.

Deviant Trials

These trials were identical to the standard trials except for the fifth letter, which was presented in a different voice (acoustic deviant) or replaced by a single number drawn from the set 1 and 9 either in the same voice as the letters (categorical deviant) or in a different voice (combined [acoustic and categorical] deviant). For categorical deviant trials, the categorical deviant was always the digit that was not sampled for the to-be-recalled list for that trial. Hence, the item selected for the deviant could not be presented visually and auditorily on the same trial.

Procedure

Prior to the beginning of the task, lab.js was used to present the information sheet, informed consent form and instruction. The following instructions were then presented.

> "In this task, you will be asked to study a series of digits. Please close any other applications on your device, and please put away and silence your cell phone. It is important to minimize any distractions in your environment, so that you can concentrate on this task. Begin this task when you know that you have at least 30 minutes of uninterrupted time to complete it. Please do not take your headphones off, and please do not adjust the volume until the study is completed. It is important that you follow the instructions, as the data may be published as part of a research project. Please press the 'Continue' button to continue".

Participants then completed a short questionnaire about their age, gender and whether they had been diagnosed with hearing loss. Participants were then asked to adjust their computer volume to a comfortable level and to put on their headphones. Thereafter, participants completed the headphone check task (see, Woods et al., 2017) to determine that they were wearing headphones (a necessary control for an online study; see, Elliott et al., 2022) and that the volume of the sound was comfortable for them. The headphone check task consisted of six trials; in each trial the three 200 Hz tones were presented to participants in each channel binaurally through their headphones. The participants were asked to identify which of the three 200 Hz tones was the softest (quietest). The task allowed for distinguishing between speakers and headphones via two manipulations: (1) by phase reversing one of the three tones between the stereo channels; and (2) by decreasing one of the three tones by 6 dB. Results from Woods et al. (2017) indicated that all participants in their study passed the headphone check task whilst wearing headphones with sound presented at a comfortable level, and 19 out of 20 did not pass when listening over loudspeakers. To succeed on the task, the participants were required to answer five of the six trials correctly and no feedback was given to them after the trials. Participants were given up to five attempts before the experiment was stopped, thereby preventing their further participation.

Serial Recall Task

Once participants had passed the headphone check, written instructions were displayed that informed participants that they would perform a serial recall task in the presence of sounds presented over their headphones. They were instructed to try to memorize the sequence of numbers as best they could and that the sound was irrelevant to their task and that they would not be tested on its content. Therefore, participants were explicitly instructed to ignore the sound and were given no information about the nature and content of the sound sequences (e.g., the presence of a deviant). Participants were also asked not to rehearse aloud during the experiment. Participants completed nine practice trials prior to starting the experiment. Participants were instructed to recall the digits in the order that they were presented, clicking on them using a mouse-driven pointer. The next trial started once the participant had selected the eight items. When the participant clicked on a digit, it disappeared from the array, indicating to the participant that the digit had been selected.

The experiment consisted of 54 trials. Forty-eight of the trials in the experiment were standard trials (no deviant) and six trials contained deviants. Deviants were presented on trials 5, 12, 20, 33, 38 and 51. Immediately after the last experimental trial, participants were presented with a sequence of three repeated letters and were asked to type in the last letter they heard. This catch-trial was embedded in the experiment as a way to ensure that participants complied with the instruction to wear headphones throughout the task.

Participants additionally completed a post-experiment questionnaire that also determined their general compliance with the task instructions (for more details, see, Elliott et al., 2022).

Within the results section, we report Cohen's *d* as a measure of effect size for pairwise comparisons and the size of these effect are interpreted as small, medium or large using Cohen's (1988) conventions. Bayes factors were also computed for all pairwise comparisons using a Cauchy prior with a scaling factor set to 1 (Rouder et al., 2009). We used the categorization scheme developed by Jeffreys (1961) and updated by Lee and Wagenmakers (2014) to define the strength of evidence. SPSS 28 (IBM Corp., Armonk, NY) was used to perform all analyses. The systematic consistency of the three statistical indicators (*p* values, effect sizes and Bayes Factors) can yield important information concerning pairwise comparisons: The Bayesian approach was adopted to yield an indicator for multiple comparisons to back-up null hypothesis significance testing (NHST) based inferences concerning the absence of reliable differences between some conditions. Since some of our key conclusions, below, rely on the observation of null effects, the Bayesian approach was adopted to provide further support for the null hypothesis (H_0).

Results

The responses to the practice trials were not scored. Figure 1 shows the proportion of correct responses, collapsed across serial position, in the deviant and standard experimental trials across the three deviant types. Serial recall performance appears to be lower for deviant as compared to standard trials. The disruptive impact of an acoustic deviant and a categorical deviant appear comparable in magnitude. However, the disruption produced by a combined deviant seems somewhat larger in magnitude than that for the acoustic deviant and categorical deviant.

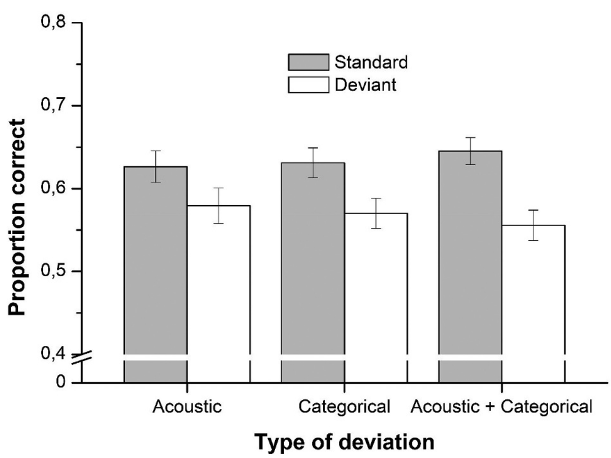

Figure 1. Mean proportion of items correctly recalled in deviant and standard (no-deviant) trials as a function of Deviant Type in Experiment 1. Error bars represent the standard error of the means.

These data were subjected to a 2 × 3 mixed ANOVA with Deviant Presence (Standard, Deviant) as the within-participant factor and Deviant Type (Acoustic, Categorical, and Combined) as the between-participants factor. This revealed a significant main effect of Deviant Presence, $F(1, 189) = 122.66$, $MSE = 0.003$, $p < .001$, $\eta_p^2 = 0.394$, indicating that serial recall performance was poorer for trials wherein deviants were present compared to standard trials for which deviants were absent. There was no main effect of Deviant Type, $F(2, 189) = 0.006$, $MSE = 0.041$, $p = .994$, $\eta_p^2 < 0.001$. However, the Deviant Presence × Deviant Type interaction was significant, $F(2, 189) = 4.403$, $MSE = 0.003$, $p = .014$, $\eta_p^2 = 0.045$.

To investigate whether the deviation effect was larger in magnitude when the deviation was on two dimensions (acoustic and categorical) compared to one dimension (acoustic or categorical), pairwise comparisons (with Bonferroni correction) were undertaken using the difference scores (standard minus deviant) for each deviation type. These revealed that the magnitude of the deviation effect was significantly greater for combined deviants compared to acoustic deviants, $p = .012$, 95% CI (.007, .078), Cohen's $d = 0.487$, BF01 = 0.212 (indicating moderate evidence for the alternative hypothesis [H_1]), but not categorical deviants, $p = .175$, 95% CI (−.008, .063), Cohen's $d = 0.350$, $BF_{01} = 1.178$ (indicating anecdotal evidence for the null hypothesis [H_0]), although a trend for greater disruption was observed for the combined deviant against categorical deviant conditions. The magnitude of the acoustic against categorical deviation effect did not differ, $p = .96$, 95% CI (−.05, .021), Cohen's $d = 0.182$, $BF_{01} = 4.407$ (indicating moderate evidence for H_0).

The size of the deviation effect (standard compared with deviant) was medium for acoustic deviation, $t(64) = 4.28$, $p < .001$, Cohen's $d = 0.535$, $BF_{01} = 0.004$ (representing strong evidence for H_1), large for categorical deviation, $t(63) = 6.794$, $p < .001$, Cohen's $d = 0.856$, $BF_{01} < 0.001$ (representing extreme evidence for H_1) and large for the combined deviation, $t(65) = 8.309$, $p < .001$, Cohen's $d = 1.031$, $BF_{01} < 0.001$ (representing extreme evidence for H_1).

Discussion

Experiment 1 showed that a deviant auditory stimulus conveying an acoustic and categorical deviation was significantly more disruptive of serial recall performance than an acoustic deviant. Furthermore, there was a numerical trend for the combined deviant to be more disruptive than a categorical deviant. This partially supports the notion that acoustic and categorical deviant effects are additive (cf., Besson et al., 1998) and is consistent with the notion that they are driven by different cognitive mechanisms (Labonté et al., 2022; Vachon et al., 2020). At the same time, the results are at odds with the view that both effects are driven by attentional capture since one might expect that the attentional capture produced by one feature (e.g., acoustic irregularity) would negate the impact of attentional capture produced by a second feature (e.g., semantic irregularity).

As reviewed in the introduction, previous research demonstrates that the categorical deviation effect, unlike the acoustic deviation effect, is not modulated by differences in working memory capacity (Labonté et al., 2022) and manipulations of other forms of top-down control such as increased task-engagement or the presence of foreknowledge (Vachon et al., 2020). Taken together, these studies and the current results suggest that the categorical deviation effect is not driven by the same mechanism that drives the acoustic deviation effect, namely attentional capture.

Another compelling way to test whether the categorical deviation effect is underpinned by attentional capture is to investigate whether it diminishes over the course of the experiment. Such a pattern is typically taken to reflect habituation of the orienting response that indexes attentional capture (Sokolov, 1963). On repeated presentation of deviant events, the deviant items become represented in the predictive model of the auditory sequence and the orienting response habituates (Öhman, 1979), thereby permitting adaptation to the environment and selective attention to present goals (Cowan, 1995; Sokolov, 1963; Waters et al., 1977). Habituation may reflect a simple learning mechanism that associates the goal-irrelevant (deviant) stimuli with no-consequence responses (Lubow, 1989). Habituation of the orienting response, which indicates that a stimulus no longer captures attention, can be observed through the diminishment of behavioral disruption produced by the deviant sound and other indices of the orienting response, such as its psychophysiological markers (Marois & Vachon, 2018; Waters et al., 1977).

Numerous studies demonstrate that the disruptive impact of an acoustic deviant diminishes over the course of an experiment (Sörqvist, 2010; Sörqvist et al., 2012; Vachon et al., 2012; see also, Cowan, 1995; Debener et al., 2002; Elliott & Cowan, 2001; Öhman, 1979; Sams et al., 1984; Waters et al., 1977), suggesting an incorporation of acoustic deviants into the predictive model of the sequence and subsequent habituation of the orienting response (Hughes et al., 2013). This reinforces the notion that attentional capture underpins the disruption produced by acoustic deviants. Previous work has shown that the acoustic deviation effect can be ameliorated by top-down control from the outset (e.g., from the very first deviant trial in a study; Hughes et al., 2013) or during the course of an experimental session. For example, Sörqvist et al. (2012) demonstrated that those with higher working memory capacity more quickly habituated to the behavioral disruption produced by acoustic deviants than their lower working memory capacity counterparts. This suggests a link between top-down cognitive control and habituation of the orienting response. If the categorical deviation effect is not tempered by top-down cognitive control, as Vachon et al. (2020) suggest, and is not the outward expression of an attentional capture mechanism, then it should not habituate over the course of an experiment.

Previous experiments that have failed to find evidence that an attentional capture mechanism underpins the categorical deviation effect have used designs wherein only a few deviants are presented in total (Labonté et al., 2022; Vachon et al., 2020). Typically, studies designed to test the presence of habituation include the presentation of multiple deviants during the course of an experiment (Sörqvist et al., 2012). Experiment 2 therefore investigates whether attentional capture underpins the categorical deviation effect, like the acoustic deviation effect, using a design wherein multiple deviant items are presented, thereby permitting an analysis of habituation.

Experiment 2

There is abundant evidence for the occurrence of habituation of attentional orienting to acoustically unexpected stimuli (Marois & Vachon, 2018; Sokolov, 1963; Steiner & Barry, 2011; Vachon et al., 2012). Experiment 2 sought to determine whether the disruption produced by a categorical deviant (Labonté et al., 2022; Vachon et al., 2020; Experiment 1), acoustic deviant (Jones & Macken, 1993; Vachon et al., 2012) and combined deviants (Experiment 1) persists or declines over the course of the experiment using a design that is sufficiently sensitive to detect habituation. If, unlike the acoustic deviation effect, the deviation effect produced by categorical change does not diminish across trials, then doubt should be cast over the notion that it is underpinned by an attentional capture mechanism. Of additional interest in Experiment 2, is disruption produced by the combined deviant: Does the disruption produced by the combined deviant diminish due to habituation to the acoustic deviant component? Such a finding might be predicted if semantic processing (e.g., of the categorical deviant) is boosted following attentional switching toward the deviant stimulus (Escera et al., 2003; Parmentier, 2008). Further, does the presence of a categorical deviant component within the combined deviant prevent habituation to the acoustic deviant component? It should be noted here that previous work (Vachon et al., 2020) demonstrates that the semantic content of the irrelevant sequence is processed regardless of any acoustic attentional capture, otherwise a categorical deviation effect would not have emerged. In Experiment 2, participants were presented with 18 deviant trials in a total of 54 experimental trials. To investigate the occurrence of habituation, we compared the deviation effects observed in the first half of the experimental trials with those in the second half of experimental trials (cf., Parmentier, 2008).

Method

With exceptions noted below, the method was otherwise identical to that deployed in Experiment 1.

Participants

One hundred and eighty-eight new participants were recruited via Prolific Academic for Experiment 2. Sixty-two adults (38 women; mean age: 26 years) were recruited for the acoustic deviant condition, 63 adults (47 women; mean age: 25 years) for the categorical condition and 63 adults (37 women; mean age: 24 years) for the acoustic and categorical deviant condition. Participants were recruited randomly to the three experimental conditions via OpenLab.

Design

A 3 × 2 × 2 mixed design was used wherein the deviant type was a between-participants factor and the presence of a deviant and the half (first vs. second half) of the experiment were within-participant factors. The independent variables were the presence of deviant trials, deviant type and the half of the experiment, and the dependent variable was serial recall task performance.

Materials and Procedure

The materials and procedure were identical to Experiment 1, with the exception that 18 out of 54 experimental trials contained a deviant. Deviants were presented on trials 2, 5, 7, 10, 12, 15, 20, 22, 25, 28, 33, 36, 38, 41, 44, 48, 51, 53.

Results

Figure 2 presents the proportion of correct responses, collapsed across serial position, in the deviant and standard trials in the first and second half of the experiment as a function of the three deviant types in Experiment 2. The presence of a deviant, regardless of type, appears to disrupt performance. The disruption produced by an acoustic deviant appears to diminish from the first to second half of the experiment, but no such reduction is evident for a categorical deviant or an acoustic and categorical deviant.

These data were submitted first to a 2 × 3 mixed ANOVA with Deviant Type as the between-participants factor and Deviant Presence as the within-participant factor to verify whether the pattern of results found in Experiment 1 was replicated in Experiment 2. The ANOVA revealed a main effect of Deviant Presence, $F(1, 187) = 144.90$, $MSE = 0.002$, $p < .001$, $\eta_p^2 = 0.437$, indicating that the presence of a deviant results in poorer serial recall performance. There was no main effect of Deviant Type, $F(2, 187) = 0.417$, $MSE = 0.047$, $p = .660$, $\eta_p^2 = 0.004$. However, there was a significant interaction between Deviant Presence and Deviant Type, $F(2, 187) = 10.780$, $MSE = 0.002$, $p < .001$, $\eta_p^2 = 0.103$.

To investigate whether the deviation effect was larger in magnitude when the deviation was on two dimensions (acoustic and categorical) compared to one dimension (acoustic or categorical), pairwise comparisons (with Bonferroni correction) were undertaken using the difference scores (standard minus deviant) for each deviation type. These revealed that the magnitude of the deviation effect was significantly greater for combined deviants compared to acoustic deviants, $p = .002$, 95% CI (.012, .069), Cohen's $d = 0.602$,

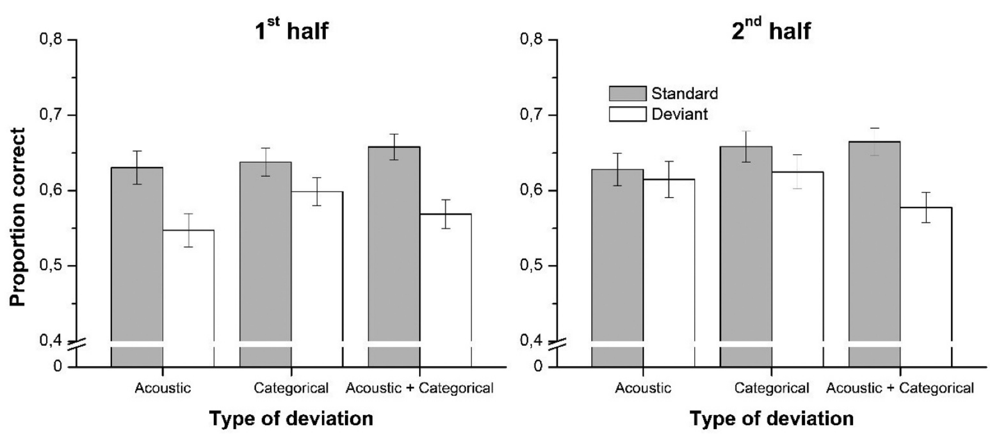

Figure 2. Mean proportion of items correctly recalled in deviant and standard (no-deviant) trials as a function of Deviant Type and Experiment Half in Experiment 2. Error bars represent the standard error of the means.

BF_{01} = 0.041 (representing strong evidence for H_1), and categorical deviants, $p < .001$, 95% CI (.024, .081), Cohen's d = 0.803, BF_{01} = 0.001 (representing extreme evidence for H_1). The magnitude of the acoustic against categorical deviation effect did not differ, p = .92, 95% CI (−.016, .040), Cohen's d = 0.180, BF_{01} = 4.448 (representing moderate evidence for H_0).

The size of the deviation effect (standard compared with deviant) was medium for acoustic deviation, $t(63) = 5.616$, $p < .001$, Cohen's d = 0.708, $BF_{01} < 0.001$ (representing extreme evidence for H_1), medium for categorical deviation, $t(65) = 4.514$, $p < .001$, Cohen's d = 0.561, BF_{01} = 0.002 (representing very strong evidence for H_1) and large for the combined deviation, $t(62) = 10.694$, $p < .001$, Cohen's d = 1.031, $BF_{01} < 0.001$ (representing extreme evidence for H_1).

To investigate whether the deviant effects diminished in the second half of the experiment, the data were submitted to a 2 × 2 × 3 mixed ANOVA with Deviant Type as the between-participants factor and Deviant Presence and Experiment Half (first vs. second) as within-participant factors. The ANOVA revealed a main effect of Deviant Presence, $F(1, 187) = 144.90$, $MSE = 0.004$, $p < .001$, $\eta_p^2 = 0.437$, showing that the presence of a deviant results in poorer serial recall performance. There was also a main effect of Experiment Half, $F(1, 187) = 14.45$, $MSE = 0.006$, $p < .001$, $\eta_p^2 = 0.072$, but not of Deviant Type, $F(2, 187) = 0.418$, $MSE = 0.094$, $p = .659$, $\eta_p^2 = 0.004$. There were significant interactions between Deviant Presence and Deviant Type, $F(2, 187) = 10.66$, $MSE = 0.004$, $p < .001$, $\eta_p^2 = 0.102$, and between Deviant Presence and Experiment Half, $F(1, 187) = 11.032$, $MSE = 0.003$, $p = .001$, $\eta_p^2 = 0.056$. There was no interaction between Experiment Half and Deviant Type, $F(2, 187) = 1.66$, $MSE = 0.006$, $p = .194$, $\eta_p^2 = .017$. However, the three-way interaction between Deviant Presence, Experiment Half and Deviant Type was significant, $F(2, 187) = 7.96$, $MSE = 0.003$, $p < .001$, $\eta_p^2 = 0.078$.

The three-way interaction was decomposed using the difference scores (standard minus deviant) for each deviation type. Pairwise comparisons (with Bonferroni correction) revealed that the magnitude of the deviation effect was significantly reduced from the first half to the second half of the experiment for acoustic deviants, $p < .001$, CI (.043, .096), Cohen's d = 0.674, $BF_{01} < 0.001$ (representing extreme evidence for H_1), but not for categorical deviants, p = .664, CI (−.020, .032), Cohen's d = 0.050, BF_{01} = 9.481 (representing moderate evidence for H_0), or combined deviants, p = .886, CI (−.025, .029), Cohen's d = 0.020, BF_{01} = 9.906 (representing moderate evidence for H_0). It is notable that the Bayesian analyses are consistent with the results of the NHST. That is, the Bayes factor indicated various degrees of evidence in favor for the null effects reported thereby strengthening our confidence that the obtained non-significant tests represent the absence of a mean difference (i.e., there is truly no reduction in the magnitude of the categorical deviation effect from the first to the second half of the experiment).

Discussion

The results of Experiment 2 clearly demonstrate that the disruptive impact of an acoustic deviant diminishes over the course of a study, while the disruptive impact of a categorical deviant and a combined deviant remains unaltered. This result is consistent with the notion that the acoustic deviation effect is produced via orienting responses (attentional capture) that diminish – that is, habituate – with repetition (e.g., Debener et al., 2002; Marois et al., 2018; Sörqvist et al., 2012). The results are inconsistent with the idea that the categorical deviation effect is also subtended by an attentional capture mechanism since, if so, it would be expected to diminish over time like its acoustic counterpart. Of particular interest is the disruption produced by the combined acoustic and categorical deviant. The failure of the effect to diminish over the course of the experiment suggests that the acoustic deviant component of the effect does not diminish when it is paired with a categorical deviant. Assuming the impact of acoustic and categorical deviants are additive, this suggests that the combination of the acoustic and categorical deviant prevents habituation to the acoustic deviant.

General Discussion

The aim of this study was to investigate whether acoustic and categorical deviation effects are underpinned by the same mechanism (attentional capture) or different mechanisms. Experiment 1 demonstrated that the magnitude of disruption of visual-verbal serial recall performance from an acoustic and categorical deviant was greater than the disruption produced by an acoustic deviant alone. This additivity of acoustic and categorical deviant effects on behavioral performance is consistent with the notion that the effects are subtended by different mechanisms (cf., Besson et al., 1998). Consistent with the notion that the acoustic deviation effect is underpinned by attentional capture, Experiment 2 revealed that the magnitude of disruption produced by acoustic deviations diminished during the course of the experiment. This is in line with the idea that repeated presentations of deviant acoustic stimuli resulted in habituation of the attentional orienting response to those stimuli (e.g., Marois & Vachon, 2018; Röer et al., 2011; Sörqvist et al., 2012; Vachon et al., 2012). In sharp contrast, however, the disruption produced by a categorical deviant or an acoustic and categorical deviant did not diminish from the start to the end of the experiment. This failure to observe habituation suggests that the categorical deviation effect is not underpinned by attentional capture and, when co-presented with an acoustic deviation, that categorical deviation prevents the orienting response to acoustic deviants to habituate.

The results of the current study add to the growing body of literature suggesting that acoustic and categorical deviation effects are supported by distinct mechanisms (Labonté et al., 2022; Vachon et al., 2020). As detailed earlier, the acoustic deviation effect is amenable to top-down control, being eliminated or reduced under conditions requiring higher task-engagement (Hughes et al., 2013; Hughes & Marsh, 2020; Marsh et al., 2020), forewarning about the presence of an acoustic irregularity in an impending to-be-ignored sequence (Hughes et al., 2013; Parmentier & Hebrero, 2013), or for individuals with a stable disposition for attentional control (high working memory capacity; Hughes et al., 2013; Labonté et al., 2022; Marsh et al., 2017; Sörqvist, 2010; but see, Körner et al., 2017). The categorical deviation effect, however, is immune to these factors (Labonté et al., 2022; Vachon et al., 2020).

The additivity of acoustic and categorical deviants as compared with acoustic deviants alone in terms of the magnitude of disruption they produce to serial recall, is consistent with the operation of two mechanisms: if acoustic deviation produced an orienting response then, arguably, no or at least very little, disruption would be produced if categorical deviants also elicited an orienting response. Further, the failure to observe diminished disruption across the course of an experiment for categorical and combined deviants, calls into question whether top-down cognitive control has the same influence over categorical deviance distraction as it does acoustic deviance distraction (Sörqvist et al., 2012). The evidence for habituation observed for acoustic deviants, however, is entirely consistent with the notion that top-down cognitive control can override acoustic deviance distraction (see also, Hughes, 2014; Hughes et al., 2013).

The results reaffirm that the model of the prevailing auditory environment, and predictions as to upcoming auditory events, not only contains acoustic features but also post-categorical, semantic features (see also, Marsh et al., 2014; Röer et al., 2019a). Further, the results support the position that to-be-ignored sound must receive semantic processing, else categorical deviations and other forms of semantic deviations (cf., Röer et al., 2019b, 2019a) would go undetected. In addition, this detection of semantic irregularities is capable of disrupting ongoing mnemonic processes. The results of the current study suggest that categorical and acoustic deviance detection must operate in parallel, with acoustic deviation having minimal influence over categorical deviance detection, and categorical deviance detection modulating the attentional capture process underpinning acoustic deviation (e.g., Experiment 2). Such a pattern of results has not been observed in the context of a seemingly related phenomenon whereby a sentence-end word disrupts performance of a concurrent serial recall task if it is semantically unexpected on the basis of the preceding context: the semantic mismatch effect. Röer et al. (2019c) demonstrated that presenting the unexpected sentence-end word in a different voice to the preceding sentential context, eliminated the semantic mismatch effect, suggesting that an acoustic deviation modulates the disruption produced by a semantic irregularity. Other evidence from the semantic mismatch paradigm, however, is consistent with the results of the current study. For example, Röer et al. (2019b) demonstrated that the effect was not subject to habituation, which also contrasts with an attentional capture account of the semantic mismatch effect.

Limitations and Future Directions

While the results of the current study fail to support the notion that attentional capture underlies the categorical deviation effect, as is the case for the acoustic deviation effect (Labonté et al., 2022; Vachon et al., 2020), a limitation of the study is that its results do not directly address the mechanism that *does* underpin the categorical deviation effect.

We suspect that the categorical deviation effect is underpinned by some low-level, language-specific mechanism. Our current research program aims to shed further light on this through behavioral and psychophysiological studies that investigate ERPs elicited by acoustic, categorical and combined deviants. We propose that the categorical deviation effect will elicit an ERP associated with the processing of violations in semantic expectancies, the N400 (Kutas & Hillyard, 1984; Proverbio & Riva, 2009), and be modulated by factors known to affect this component (e.g., word frequency and repetition; Rugg, 1990; Van Petten & Kutas, 1990; Van Petten et al., 1991; Besson & Kutas, 1993). Further, unlike acoustic deviants, we propose that categorical deviants will fail to trigger the ERP index of involuntary attentional orienting, the P3a

(Friedman et al., 2001). Like Besson et al. (1998) we expect that categorical and acoustic deviants will be independently processed and thus a P3a and an N400 should be observable for the combined deviant.

For habituation designs, we expect that the N400 should remain undiminished for repetition of categorical deviants, but that the P3a should diminish following repetition of acoustic deviants unless it is combined with a categorical deviant. This is because the presence of categorical deviation appears to prevent habituation of the orienting response to acoustic change (Experiment 2). However, the reason that habituation occurs to acoustic deviations, but the impact of a combined deviation does not diminish over the course of the experiment remains unclear. If acoustic and categorical deviants are additive in their effects, then it might be expected that subtracting the impact of an acoustic deviation (through habituation) from the combined deviants would leave only the contribution from the category deviation and thereby a diminished effect from the first to second experimental block. Although speculative, it is possible that the failure to observe habituation to the combined deviant could be due to the categorical deviant altering the processes involved in detecting acoustic irregularities, perhaps by lowering or altering the detection threshold (cf., Schröger, 1997).

Up to this point we suggest that the categorical deviant is underpinned by a mechanism other than attentional capture. However, on the basis of existing data it cannot be ruled out that the categorical deviant effect, like the acoustic deviant effect, is also undergirded by attentional capture, but for some reason evades top-down control. One way to address this possibility is to undertake a psychophysiological study of the two effects and investigate ERP correlates of the orienting response. These include mismatch negativity (MMN), P3a and re-orientation negativity (RON; e.g., Näätänen, 1992; Schröger & Wolff, 1998). Respectively, these are associated with pre-attentive change detection (MMN), involuntary attentional switching (P3a), and the reorienting of attention (RON). It has been suggested that WMC and higher task-encoding load may potentiate a blocking mechanism whereby detection of an acoustic deviant still occurs but the actual switch of attention to the deviant can be overridden. It remains possible that a categorical deviant may produce attentional capture, but evade the blocking mechanism. If this is true then one might expect an intact MMN but a reduced P3a component for acoustic deviants under situations of cognitive control, but intact MMN and P3a components for categorical deviants. Further, it is possible that categorical against acoustic deviants may demonstrate a more pronounced, or delayed, RON, reflecting a greater difficulty reorienting to the task following capture.

Another potential way to disentangle the acoustic and categorical deviants could be to examine differences in the pupillometry dilation response (PDR). A growing body of evidence demonstrates that unexpected deviant sounds trigger the PDR (e.g., Liao et al., 2016; Marois & Vachon, 2018; Wetzel et al., 2016; Zhao et al., 2019) that is taken to reflect involuntary attentional diversion (Liao et al., 2016; Marois et al., 2019, 2020; Marois & Vachon, 2018; Wang & Munoz, 2015). The PDR is implicated in orienting behavior (e.g., Sara, 2009) and demonstrates characteristics of the classical orienting response, including habituation with repetition of the orienting response-eliciting stimulus (Marois & Vachon, 2018; Steiner & Barry, 2011). However, the PDR has not been investigated in the categorical deviation effect. If the PDR is evoked for both acoustic and categorical deviants, this would suggest that attentional capture underpins both effects. However, if the PDR selectively occurs for acoustic deviants then this would offer further support against an attentional capture account of the categorical deviation effect.

Another puzzle that requires solution is to what purpose the categorical deviation effect serves. Why, unlike the case for acoustic deviants, does habituation not occur to categorical deviants? The acoustic deviation effect is undoubtedly the manifestation of a phylogenetically older mechanism that presumably evolved to signal potentially important events that require action (Johnston & Strayer, 2001). The categorical deviation effect, however, must reflect a mechanism that developed later with the evolution of language. If the primary purpose of acoustic deviation detection is to locate danger (or opportunity), then it is possible that the association of the acoustic deviant to a no-consequence response within the laboratory setting, can result in habituation. However, if the purpose of a categorical deviation detection is not to monitor danger (or opportunity), then it is inconsequential whether a categorical deviant becomes associated with no-consequence responses (cf., Lubow, 1989). Note that we are not suggesting that habituation to acoustic deviants results in a failure to detect acoustic irregularities. Rather, we are suggesting that it reflects the action of a blocking mechanism that prevents the actual switch of attention to that specific capturing event (e.g., Sörqvist & Marsh, 2015) or alternatively cuts short the evaluation of a deviant event thereby permitting a speedier resumption of the focal task (e.g., Parmentier et al., 2008).Although it is tempting to ascribe an evolutionary purpose for categorical deviance detection, we note that its link with evolution might be indirect and that many modern adaptations to do with language processing are far removed from evolutionary mechanisms, or may have co-evolved as offshoots of them. It is possible that categorical deviance detection may be a by-product of another phenomenon, just as an interference-by-process arises due to a clash of serial order representations: one derived from the deliberate serial rehearsal of to-be-remembered items and another that arises as a by-product of a pre-attentive process that integrates changing sounds into the same stream (perceptual streaming [Bregman, 1990]; see, Jones, 1993). In short, the purpose of categorical deviation detection will remain unclear until the mechanism underlying the effect is fully understood.

From a methodological point of view, the study was well-controlled. Nevertheless, it was undertaken online, accessed by many different network connections in many different environmental contexts on a presumably large variety of computer and audio systems. Although there is evidence that auditory distraction can be studied online, future work might seek to compare in-person with online data collections (cf., Elliott et al., 2022).

Conclusion

The present study aimed to investigate whether the acoustic and categorical deviation effects reflect the operation of two distinct mechanisms. The results suggest that distraction by task-irrelevant sound caused by unexpected semantic changes (categorical deviants) cannot be explained by the same attentional capture mechanism that adequately explains disruption produced by acoustic deviants (Hughes et al., 2005, 2007; Röer, et al., 2019). Evidence, therefore, points to a functionally distinct form of auditory distraction (see also, Labonté et al., 2022) whose specific characteristics, and interactions with the attentional capture mechanism may be disentangled through future behavioral and (electro)physiological research.

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ORCID

François Vachon http://orcid.org/0000-0001-5282-6048
John E. Marsh http://orcid.org/0000-0002-9494-1287

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