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Distraction by auditory categorical deviations is unrelated to working memory capacity: Further evidence of a distinction between acoustic and categorical deviation effects

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Abstract

Introduction

A rare and unexpected change (or deviation) in the properties of an irrelevant auditory background can disrupt performance of a visual focal task via attentional capture. Although this effect is typically caused by a change in the acoustic properties of the sound, recent evidence has shown that a change in (semantic) category within a sound stream could also disrupt ongoing cognitive activity. The present study aimed to investigate the functional characteristics of this recently discovered categorical deviation effect.

Methods

In two experiments, an irrelevant sound stream was presented while participants performed visual serial recall. We examined whether working memory capacity (WMC) is associated with susceptibility to distraction by an unexpected change in category within the sound. Acoustically deviating sounds were also presented to compare the categorical and acoustic deviation effects directly.

Results

Both experiments revealed that the categorical deviation effect was not correlated with WMC. The expected relationship between WMC and the acoustic deviation effect was observed, but the acoustic and categorical deviation effects were unrelated.

Discussion

Our results constitute new evidence of a distinction between the acoustic and categorical deviation effects despite their apparent similarity. They also suggest that the categorical deviation effect is not underpinned by attentional capture.

Keywords: auditory distraction; semantic processing; working memory capacity; attentional capture; auditory deviation

Introduction

A rare and unexpected change in the properties of an irrelevant auditory background can disrupt the performance of a task, a phenomenon known as the deviation effect (see Escera et al., 1998; Hughes et al., 2005; 2007; Sörqvist, 2010; Vachon et al., 2017). The typical explanation for this effect implies that the attentional focus is temporarily directed toward the irrelevant deviant stimulus, thereby impacting the ongoing mental activity (Cowan, 1995; Escera et al., 1998; Schröger, 1997; Sokolov, 1993). In most demonstrations of the deviation effect, attentional capture is caused by an irregularity in the low-level properties of the surrounding sound, such as an unexpected change in pitch (e.g., Sörqvist, 2010), spatial location (e.g., Vachon et al., 2017), or timing (e.g., Hughes et al., 2005), or an unforeseen repetition within an otherwise non-repeated auditory stream (e.g., Marois et al., 2020). The impairment of task execution caused by such a violation in the pattern shaped from the physical features of the recent auditory background can be referred to as the *acoustic deviation effect*. Recently, a new form of deviation effect has been brought to light. Vachon and colleagues (2020) have shown that a change of category within a sequence of irrelevant spoken items (e.g., a spoken letter inserted within a series of spoken digits) can hinder performance of the focal task, even if the deviant item has no specific acoustic properties that sets it apart from the other speech tokens. This *categorical deviation effect* occurs in spite of the deviant carrying no arousing (e.g., taboo words; see Röer et al., 2017) or personally-significant features (e.g., one’s own name; see Röer et al., 2013). The fact that an unexpected change in the semantic content of unattended neutral sound disrupts performance of an ongoing cognitive task suggests that the auditory background not only undergoes automatic processing of its physical properties (cf. Schröger, 1997; Sokolov, 1963), but is also processed in a post-categorical fashion (Vachon et al., 2020; see also Marsh et al., 2014).

Having only recently been discovered, the specific mechanisms underlying the categorical deviation effect remain to be clarified. Because both the categorical and acoustic deviation effects are engendered by an infrequent and unexpected variation in an irrelevant auditory stimulation, they could be expected to operate in a comparable way. However, despite their similarity, evidence so far suggests that these two effects may not be functionally equivalent. The magnitude of the disruption caused by the occurrence of an acoustic deviation has previously been shown to be altered by two factors deemed to reflect top-down cognitive control, namely the level of focal-task engagement (Hughes et al., 2013; Marsh et al., 2020; Sörqvist & Marsh, 2015) and foreknowledge about an imminent deviant stimulus (e.g., Horváth & Bendixen, 2012; Hughes et al., 2013; Sussman et al., 2003). Such a modulation of the response to acoustic deviants is consistent with the widely supported hypothesis of the attentional nature of the acoustic deviation effect. Indeed, distraction by attentional capture is typically considered amenable to top-down cognitive control (e.g., Awh et al., 2012; De Jong et al., 1999). Yet, in four different experiments, Vachon and colleagues (2020) have shown that task engagement and prior knowledge of an imminent deviation did not affect the magnitude of the categorical deviation effect. Therefore, despite the apparent similarity between acoustic and categorical deviation effects, these results suggest that auditory distraction by a categorical deviation may not be subtended by attentional capture. This hypothesis is further supported by a recent investigation showing that, unlike acoustic deviants, the behavioral response to categorical deviants does not habituate (Littlefair et al., this volume).

Vachon and colleagues' (2020) initial investigation about the categorical deviation effect revealed that this phenomenon was immune to top-down influences through manipulations that aimed to temporarily promote participants' ability to focus on the task at hand and ignore the irrelevant auditory background. Another way in which the role of top-down cognitive control in the susceptibility to disruption by categorical deviations can be examined is through analyses of stable dispositions for attentional control – as reflected by working memory capacity (WMC) measurements. According to the executive attention view of WMC (Engle, 2002; Kane et al., 2004), WMC is deemed to reflect inter-individual differences in the ability to control attention. Hence, this construct is more about using attention to maintain or suppress information than memory per se. Typically, WMC is assessed with complex-span tasks (e.g., the operation span task; Turner & Engle, 1989) that combine short-term memory processes (such as those involved in serial recall) with a concurrent distractor task. Therefore, the main difference between low- and high-WMC individuals is their ability to use cognitive control to stay focused on the primary task in the face of distraction (e.g., Unsworth & Engle, 2007). According to Engle (2002), "greater WM capacity also means greater ability to use attention to avoid distraction" (p. 20). Consistent with this standpoint, resistance to the acoustic deviation effect has been shown to be positively related to WMC as measured with the operation span task (Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010; Sörqvist, Nöstl, & Halin, 2012; but see Körner et al., 2017). Similarly, Sörqvist, Stenfelt, and Rönnberg (2012) reported that WMC was related to the size of the auditory-brainstem response to deviant sound, suggesting that high WMC helps suppressing irrelevant sensory information, hence reducing distraction by attention capture (see also SanMiguel et al., 2008; Sörqvist et al., 2016; Zhang et al., 2006). That WMC can predict the magnitude of the acoustic deviation effect has been taken as an indication that disruption by acoustic deviants is open to top-down cognitive control (see Hughes, 2014; Mahajan et al., 2020; Sörqvist et al., 2013). An examination of the relationship between WMC and the size of the categorical deviation effect could, therefore, help confirm the apparent immunity of this effect to top-down influences.

The current study sought to increase our understanding of the recently discovered categorical deviation effect by taking a closer look at its functional characteristics. In Experiment 1, we examined if, as with acoustic deviations, WMC attenuates distraction by categorical deviations. In Experiment 2, we took this examination one step further by making a direct comparison between the categorical deviation effect and its acoustic analog.

Experiment 1

The first experiment employed an individual differences approach to determine whether cognitive control abilities were associated with the magnitude of the disruption caused by a categorical deviation. More precisely, we examined whether the distracting impact on cognitive performance of a change in category within a sequence of irrelevant spoken items would be modulated by WMC. The potential effect of such categorical deviation was measured via performance achieved on a serial recall task. If the categorical deviation effect is not amenable to top-down control, then individual differences in attention control capabilities—as indicated by WMC—should not be related to individual differences in distractibility from categorical deviants.

Method

Participants. Fifty-one students or employees from Université Laval (34 females and 17 males; mean age: 24 years) volunteered to take part in the experiment in exchange for a small honorarium. All participants were native French speakers and reported normal or corrected-to-normal vision and hearing. The experiment was approved by the ethics committee of Université Laval and written consent was obtained from all volunteers prior to testing.

Materials. The presentation of all stimuli was controlled using E-Prime 2.0 Professional (Psychology Software Tools). This software was also used to display instructions and record participants' responses. Visual stimuli were presented on a PC computer monitor situated approximately 60 cm away from participants, and auditory stimuli were presented through Sennheiser headphones.

***Serial recall task*.** All stimuli used in the serial recall task were the same as those used by Vachon and colleagues (2020, Experiment 1). Each visual sequence included eight digits taken without replacement from the digit set 1–9. The order of the digits in the sequence was determined quasi-randomly, with the constraint that successive digits were not adjacent integers. Items were approximately 2.39° in height and were presented sequentially in a black Times New Roman font at the center of a white background. Each digit was presented for 250 ms with an interstimulus interval of 500 ms.

The irrelevant auditory stimuli consisted of French spoken letters and digits. The letter set included the letters B, F, H, K, M, Q, R, X, and Z, whereas the digit set included all digits from 1 to 9. All items were spoken in the same male voice at an approximately even pitch and edited to a duration of 250 ms using SoundForge (Sony). An analysis of the physical properties of the spoken stimuli used in this experiment showed no systematic acoustic or phonological discrepancies between the two sets of items (see Appendix A of Vachon et al., 2020, for more details). Therefore, the occurrence of a change in category within the auditory stream did not simultaneously lead to an acoustic deviation. Auditory stimuli were combined into irrelevant sound sequences of eight items that were presented binaurally. Two types of to-be-ignored (TBI) sequences were created. In the *standard* sequences, items were randomly selected without replacement from the letter set (e.g., K-X-Q-M-R-B-F-Z). The *deviant* sequences followed the same structure, but the sixth letter was replaced by one of the nine items of the digit set (e.g., K-X-Q-M-R-*6*-F-Z). As with the visual stimuli, the interval between spoken items was 500 ms. Therefore, visual and auditory stimuli were always presented synchronously. Care was taken to ensure that a given digit was never presented simultaneously in to-be-remembered (TBR) and TBI sequences. An answer booklet was used to collect participants' written responses to the serial recall task. The booklet was divided into 82 rows of eight blank squares.

WMC task. To measure WMC, we used Foster and colleagues' (2015) version of the automated operation span task. We translated the task into French and increased the duration of the feedback displayed after each trial to ensure participants had enough time to read it. The main goal of this task was to recall the serial order of letters taken without replacement from a set of 12 letters (F, H, J, K, L, N, P, Q, R, S, T, and Y). The TBR letters were presented sequentially at the center of the computer monitor and were 1.15° in height. Between the presentation of each TBR item, participants performed a visual distractor task involving simple mathematical verification problems.

Procedure. After providing their written informed consent, participants were taken to a sound-attenuated booth wherein they sat in front of the computer. Participants always completed the serial recall task first. Written instructions were displayed on the computer monitor. Instructions were also provided verbally by the experimenter to ensure that participants were familiar with them. In this situation the experimenter could also answer any questions the participants might have. Participants were informed that they would perform a serial recall task while sound would be presented over the headphones. They were told that the sound was irrelevant to their recall task and that they would not be tested on its content. Participants were therefore asked to ignore the sound and were not informed of the presence of deviant stimuli within the irrelevant auditory sequences. They were also asked not to rehearse aloud during the experiment. All participants were tested individually and were left alone in the room once the experimenter made sure that they put on the headphones. Participants then completed two standard practice trials followed by two experimental blocks of 40 trials each. Each trial was presented at a pre-set pace and consisted of the simultaneous presentation of a visual TBR and an auditory TBI sequence.

Fifty ms following the offset of the visual and auditory sequences, a brief flash on the screen signaled to the participants that they should begin to write out the TBR digits in the appropriate row of the answer booklet. They were informed that they had 15 s to write the digits in their order of presentation before the first item of the next TBR sequence appeared on the screen. They could either leave a blank space or take a guess if they were unsure of the digit that was presented at a certain position. Thirteen seconds into the 15 s of writing time, participants heard a 500-ms tone over the headphones to signal that they should look at the computer screen in preparation for the upcoming trial. Each block included 34 standard trials and six deviant trials. The standard and deviant sequences were presented in a quasi-random order, with the constraints that two deviant trials could not be adjacent and that each block began with at least three standard trials. All participants completed the same experimental blocks in a counterbalanced order. In one block, the deviant sounds were in Trials 7, 15, 22, 27, 33, and 38, whereas in the other block, they were in Trials 6, 12, 18, 22, 29, and 37.

For the operation span task, participants first practiced the recall and distractor phases separately before performing three practice trials followed by 15 experimental trials. Practice and experimental trials followed the same structure, which involved the presentation of a mathematical verification and a TBR letter in alternation. Each trial could be 3, 4, 5, 6, or 7 letters in length. When all the items of a TBR sequence had been presented, the complete set of letters appeared in a 3 × 4 matrix. Using the mouse, participants selected the letters that were part of the just-presented sequence in their order of appearance. The operation span task was divided into three experimental blocks of five randomly presented trials (one for each possible list length). Consequently, 75 letters had to be recalled in total, and participants were unaware that the trials were blocked. Overall, the experiment lasted approximately 60 minutes (40 minutes for the serial recall task and 20 minutes for the operation span task).

Measures and analysis. The main outcome of the experiment was serial recall performance. It was calculated using a strict criterion whereby an item had to be recalled in its original presentation position to be recorded as correct. The mean percentage of items correctly recalled was calculated separately for standard and deviant trials and compared between both conditions using a paired-samples *t*-test. We also calculated the difference score between standard and deviant trials and examined whether this measure correlated with WMC using Pearson’s correlation.

WMC was operationalized using participants’ operation span score, which represented the total number of letters included in every perfectly recalled list (i.e., absolute score, see Unsworth et al., 2005). This score could range from 0 to 75. To confirm that participants were equally involved in both components of the operation span task, we computed mean performance on the mathematical verifications and examined the association between this variable and the operation span score. This verification was conducted because a strong negative association between these variables could indicate that high operation span scores were obtained at the expense of active engagement in the distractor task (or vice versa). Finally, as WMC reflects the ability to maintain information in memory in the face of distraction, overall serial recall performance in the presence of distracting sounds was expected to be positively correlated with the operation span score. Therefore, we tested this relationship using Pearson's correlation to confirm the sensitivity of our index of WMC.

Cohen's *d* was reported as a measure of effect size for all pairwise comparisons, and the strength of correlations was interpreted using Cohen's (1988) conventions. To strengthen our confidence in the results of null hypothesis significance tests, Bayes factors were calculated for all pairwise comparisons and correlation analyses using a Cauchy prior with a scaling factor set to 1 (Rouder et al., 2009). The strength of evidence was defined using the categorization scheme created by Jeffreys (1961) and slightly updated by Lee and Wagenmakers (2013). All analyses were performed using SPSS 27 (IBM Corp., Armonk, NY).

Results

All variables of interest were screened for the presence of outliers (± 3.29 *SD*s from the mean; Tabachnick & Fidell, 2013), but no outlying cases were found.

Means comparisons. Figure 1 presents the percentage of digits correctly recalled in standard and deviant trials. Categorical deviants seemed to disrupt serial recall performance, which was confirmed by the paired-samples *t*-test, $t(50) = 3.66$, $p = .001$, Cohen's $d = 0.512$. The Bayes factor was $BF_{01} = 0.027$, representing very strong evidence against the null hypothesis (H_0).

Correlations. The difference in serial recall performance between standard and deviant trials (i.e., the size of the categorical deviation effect) was 2.93% ($SD = 5.72$). There was no significant association between the size of the deviation effect and the operation span score, *r*(49) = .005, *p* = .972 (see Figure 2). The Bayes factor of BF_{01} = 9.114 showed moderate evidence in favor of H_0. Mean performance on the operation span distractor task was high (*M* = 94.04%, *SD* = 3.32%), suggesting that participants did not attempt to recall the TBR items at the expense of their performance on the mathematical verifications. Accordingly, there was a significant and moderate positive correlation between the operation span score and performance on the distractor task, *r*(49) = .403, *p* = .003, and the Bayes factor indicated moderate evidence against H_0 (BF_{01} = 0.128). Moreover, there was a significant and moderate positive correlation between the operation span score and serial recall performance on all trials, *r*(49) = .415, *p* = .002. The Bayes factor of BF_{01} = 0.096 showed strong evidence against H_0.

Discussion

The magnitude of the disruption caused by an acoustic deviation has been shown to be negatively correlated with performance on the operation span task, and thus with WMC (Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010). This relationship suggests that the acoustic deviation effect can be modulated by the ability to control attention, which is consistent with the assumed attentional origin of this phenomenon (Cowan, 1995; Escera et al., 1998; Schröger, 1997; Sokolov, 1993). In their initial demonstration of the (seemingly comparable) categorical deviation effect, Vachon and colleagues (2020) showed that this novel type of auditory distraction was not susceptible to top-down cognitive control. While they came to this conclusion by manipulating task difficulty and prior knowledge of the occurrence of a deviant sound, the current experiment aimed to conceptually replicate their results using a new approach focussing on stable cognitive control abilities. More specifically, we examined whether the distraction caused by a categorical deviation was associated with WMC. This approach also allowed us to determine whether the acoustic and categorical deviation effects were similarly related to WMC, and therefore, whether they seemed to be functionally equivalent. The results showed a significant positive correlation between WMC and overall performance on the serial recall task. However, a non-significant and near-zero correlation was found between WMC and the magnitude of the disruption caused by the occurrence of a categorical deviant. Like Vachon and colleagues' (2020) results, the findings from Experiment 1 represent further evidence of the non-sensitivity of the categorical deviation effect to top-down control. Therefore, despite the apparent similarity between this auditory distraction effect and the better-known acoustic deviation effect, accumulating evidence suggests that they may not be subtended by the same mechanisms. Indeed, if acoustic and categorical deviation effects shared a common origin, the impact of a categorical deviation would likely also be modulated by WMC.

Experiment 2

Experiment 1 suggests that the categorical deviation effect is independent from cognitive control. Because this conclusion is based on a null effect obtained using a relatively small sample, we wanted to replicate the results with an improved design, starting with an increase in sample size. Moreover, in the context of auditory distraction, WMC has been almost exclusively assessed using the operation span task (see Sörqvist et al., 2013). Yet, Foster and colleagues (2015) stated that:

> a single indicator of WMC cannot be considered a measurement of WMC itself as the task contains variance from both WMC and the task. Therefore, to draw specific conclusions about WMC researchers should use multiple indicators to create either a composite or factor score of the WMC construct that consists of the variance shared between two or more complex span tasks (p. 227).

Following this advice, we assessed WMC using three complex span tasks. In addition to operation span, we also used symmetry span (serial recall of visuospatial patterns separated by distracting symmetry judgments), and rotation span (serial recall of arrows of different lengths pointing in different directions interspaced with distracting judgments of rotated letters). Although each complex span score was measured individually, we also computed a composite score encompassing the score achieved at the three tasks to obtain a global indicator of WMC. This indicator allowed us to determine whether the (lack of) relationship between WMC and the size of the categorical deviation effect still holds when moving away from the traditional index of WMC and turning to a more comprehensive measure.

Finally, Experiment 2 included two types of deviant trials, involving either a categorical deviation (a letter among digits) or an acoustic deviation (one of the digits spoken in a different voice). This approach was used not only to directly compare the categorical deviation effect to its acoustic counterpart, but also to confirm the presence of a negative correlation between the magnitude of the disruption caused by an acoustic deviation and WMC. Although this relationship has been demonstrated many times (see Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010), it has recently been brought into question by Körner and colleagues (2017), thereby emphasizing the need for a replication. Because the susceptibility to distraction by acoustic deviants is moderated by the capacity to exert top-down cognitive control (see Hughes, 2014), we expected to find a significant negative relationship between WMC and the size of the acoustic deviation effect (cf. Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010).

Method

The method was identical to that employed in Experiment 1, except as noted below.

Participants. Participants were 72 new volunteers (44 females and 28 males; mean age: 24 years) with the same characteristics as those who took part in Experiment 1.

Materials. In Experiment 2, we reversed the category from which standard and deviant spoken items were taken in order to generalize the results obtained in Experiment 1 to a context where the deviant did not come from the same category as the TBR materials. Therefore, both TBR (visual) and TBI (auditory) sequences were now composed of eight digits. Auditory items were generally spoken in a male voice, and two types of deviant trials were created. In *acoustic deviation* trials, the deviant sound was another digit, but spoken in a female voice. In *categorical deviation* trials, the deviant consisted of a letter spoken in the same male voice as the other sounds. The answer booklet used to collect participants' responses was divided into 122 rows of eight blank squares.

To assess WMC, we used Foster and colleagues' (2015) version of three complex span tasks (i.e., operation span, symmetry span, and rotation span). To avoid increasing administration time too much, we employed the shortened version of these tasks, which can also be used to assess WMC accurately (Foster et al., 2015). Each complex span task consisted in recalling the serial order of sequences of items. These items were either letters (operation span), arrows of two different lengths pointing in various directions (rotation span), or locations of red squares within a 4 × 4 grid (symmetry span). Between the presentation of each TBR item, participants performed a distractor task which consisted in solving a mathematical problem (operation span), determining whether a rotated letter was presented correctly or was a mirrored image of the letter (rotation span), or judging whether the design created by filling an 8 × 8 grid with some black squares was symmetrical along its vertical axis (symmetry span; see Figure 1 of Foster et al., 2015, for a schematic representation of the three tasks).

Procedure. The serial recall task involved four blocks of 30 trials, their order being counterbalanced across participants. Each block consisted of 25 standard trials and 5 deviant trials (either 2 or 3 of each type), making 120 trials in all. The acoustic deviation trials were Trials 6 and 18 (Block A), Trials 6, 17, and 22 (Block B), Trials 13 and 30 (Block C), and Trials 10, 19, and 22 (Block D). The categorical deviation trials were Trials 12, 22, and 30 (Block A), Trials 9 and 29 (Block B), Trials 5, 16, and 21 (Block C), and Trials 6 and 28 (Block D). There were two standard practice trials before the first block.

For each of the three complex span tasks, participants started by practicing the recall and distractor phases separately. They then performed three practice trials involving both phases in alternation (as in experimental trials) before completing a single experimental block. In the operation span task, the experimental block comprised five randomly presented trials of 3, 4, 5, 6, or 7 letters in length. In the rotation and symmetry span tasks, the experimental block comprised four randomly presented trials of 2, 3, 4, or 5 arrows (rotation) or squares (symmetry) in length. When all the items of a sequence had been presented, the complete set of items appeared on the screen. Using the mouse, participants had to select the ones that were part of the just-presented sequence in their order of presentation. Each list length appeared only once in each experimental block. The order of the complex span tasks was counterbalanced across participants. The experiment lasted approximately 90 minutes (60 minutes for the serial recall task and 30 minutes for the complex span tasks).

Design and measures. Serial recall performance was computed separately for the three types of trials and was compared using a repeated-measures ANOVA with the 3-level factor Type of trial (standard, acoustic deviation, and categorical deviation). Eta squared is reported as a measure of effect size. We examined whether the size of each deviation effect was correlated with measures of WMC using the score on each complex span task as well as a composite score consisting of the mean performance on the three tasks. For both types of deviants, the size of the deviation effect was computed by subtracting mean performance on deviant trials from mean performance on standard trials. The complex span scores were calculated by summing the number of items in every perfectly recalled list. Therefore, the score could range from 0 to 25 in the operation span task, and from 0 to 14 in rotation and symmetry span tasks. A composite score, reflecting the average performance on the three complex span tasks, was computed by converting each span score into a percentage (i.e., dividing the obtained score by the maximum score and multiplying by 100) and then by averaging the three obtained percentages. This method allowed each span score to have the same weight in the composite score. We also calculated performance on each distractor component of the span tasks to ensure that participants were actively engaged in them. Finally, we examined the correlation between each of these scores and the score obtained on the associated recall component of the span tasks.

Results

Four participants were removed from the analyses because of a failure in recording data in the symmetry span task. Therefore, all analyses were carried out on 68 subjects. All variables of interest were screened for outliers, but no cases were more than 3.29 *SD*s apart from their respective mean.

Means comparisons. Figure 3 illustrates the percentage of digits correctly recalled in standard as well as in both types of deviant trials. Recall appeared to be poorer on deviant trials, regardless of whether the deviation was acoustic or categorical in nature. This pattern of results was confirmed by a repeated-measures ANOVA revealing a main effect of Type of trial, $F(2, 134) = 25.96$, $p < .001$, $\eta^2 = .279$. Multiple comparisons showed that performance was significantly higher on standard trials than in the presence of any type of deviant (*p*s < .001, Cohen's *d*s ≥ .826). The Bayes factors indicated extreme evidence against H_0 ($\mathrm{BF}_{01} \leq 2.91 \times 10^{-7}$). No difference was found between the two types of deviant trials (*p* = .807, Cohen's *d* = .030). Therefore, acoustic and categorical deviations disrupted serial recall performance to the same extent, which was further supposed by a Bayes factor of $\mathrm{BF}_{01} = 10.716$ showing strong evidence for H_0 when comparing performance on both types of deviant trials.

Correlations. Table 1 presents the mean and standard deviation for the two deviation effect sizes and the four WMC measures (i.e., each of the three span scores and the composite score). These measures were used in the correlational analyses. It is noteworthy that mean performance on the distractor tasks was high (operation span: *M* = 93.94%, *SD* = 5.10%; rotation span: *M* = 91.49%, *SD* = 10.34%; and symmetry span: *M* = 93.70%, *SD* = 10.29%). Furthermore, there were significant and moderate positive correlations between each span score and performance on the associated distractor task (*r*s ≥ .300, *p*s < .013), suggesting that participants' attempt to recall the TBR items did not occur at the expense of their level of engagement in the distractor task. The Bayes factors showed moderate ($\mathrm{BF}_{01} = 0.153$), very strong ($\mathrm{BF}_{01} = 0.015$), and anecdotal ($\mathrm{BF}_{01} = 0.490$) evidence against H_0 for the operation, rotation, and symmetry span tasks, respectively. As expected, mean performance on all trials of the serial recall task was positively and moderately correlated with the composite span score, *r*(66) = .316, *p* = .009, although the Bayes factor suggested only anecdotal evidence against H_0 ($\mathrm{BF}_{01} = 0.344$).

Table 2 presents the Pearson's correlation coefficients between the size of the two types of deviation effect and the various WMC measures as well as the associated Bayes factors. The relationship between the magnitude of each deviation effect and all WMC measures is also illustrated in Figure 4 (for the acoustic deviation effect) and Figure 5 (for the categorical deviation effect). Consistent with previous studies (e.g., Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010), there was a significant and moderate negative relationship between the magnitude of the acoustic deviation effect and the operation span score. The Bayes factor indicated moderate evidence against H_0. This significant correlation also extended to the symmetry span and composite scores, but the results of the Bayesian analysis were less conclusive and showed anecdotal evidence both against and in favor of H_0, respectively. On the other hand, and consistent with the findings of Experiment 1, no significant correlation was found between the magnitude of the categorical deviation effect and any of the WMC measures. Accordingly, all Bayes factors indicated moderate evidence in favor of H_0. Interestingly, the size of the two deviation effects did not correlate, with the Bayesian analysis indicating strong evidence in favor of H_0.

Merging of the two experiments. The correlations observed between overall recall performance and WMC as well as between the magnitude of the acoustic deviation effect and WMC suggest that our experiments had enough statistical power to detect significant associations between variables of interest. Still, even with the increase in sample size from Experiment 1 to Experiment 2, the fact remains that sample size can be considered relatively small. As an exploratory analysis, we decided to combine both experiments and observe the relationship between the magnitude of the categorical deviation effect and WMC using all 119 participants. We acknowledge that such a combination is not optimal given the differences in TBI items and measures of WMC between the two experiments. The goal of this exploratory analysis was solely to give an idea of the relationship observed between disruption by a categorical deviation and WMC with the largest sample available. Only the operation span score was used for both experiments; therefore, the WMC score associated with Experiment 2 is that of the shortened operation span task. The operation span score from Experiment 1, which could go up to 75, was divided by 3 so that the WMC estimators were on the same scale (0–25) in both experiments. Even with this larger sample size, no significant relationship was observed between WMC and the size of the categorical deviation effect, $r(117) = -.063$, $p = .495$. The Bayes factor indicated strong evidence in favor of H_0 ($BF_{01} = 10.929$).

Discussion

Being the first direct comparison of the categorical and acoustic deviation effects (see also Littlefair et al., this volume), the present experiment revealed that the two phenomena differed with regard to their relationship with WMC. Consistent with previous demonstrations (Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010, but see Körner et al., 2017), we showed that individuals with higher WMC tend to be less sensitive to acoustic deviants than their low-WMC counterparts. Such a negative correlation was found not only with operation span score, as in previous studies, but also with symmetry span score as well as with a composite score of the three complex span tasks. Conversely, we found no relation between any measure of WMC and susceptibility to categorical deviants. Such findings suggest that distraction caused by acoustic deviations is amenable to top-down control (cf. Hughes, 2014) whereas that produced by categorical deviations is not. Moreover, the additional analysis conducted using participants from both experiments strengthens the evidence that WMC is not related to the disruption caused by a categorical deviation. This absence of relationship between the categorical deviation effect and WMC is consistent with results from Vachon and colleagues (2020) showing that the phenomenon is independent from top-down control. The present experiment not only revealed that the two forms of deviation effect are differentially related to WMC, but also that they are not interrelated. This result further supports the hypothesis that the two effects do not share the same origin.

General Discussion

This study aimed to deepen our understanding of the functional characteristics of a recently discovered auditory distraction phenomenon whereby a change in category within an irrelevant and semantically neutral auditory stream disrupts ongoing cognitive activity. In Experiment 1, we examined whether the size of this categorical deviation effect was related to WMC, as is the case for the better-known acoustic deviation effect (Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010). Because the results showed no correlation between disruption by a categorical deviant and WMC, Experiment 2 aimed to replicate these findings while also contrasting both types of deviation effect directly. The expected (negative) correlation between WMC and the size the acoustic deviation effect was observed, but again, the results revealed no correlation between WMC and the magnitude of the categorical deviation effect. Similarly, the size of the two effects did not correlate, which strengthens the hypothesis of a distinction between these two forms of auditory distraction. Not only does our study show for the first time that the categorical deviation effect is unrelated to WMC as operationalized by the classic operation span task, but we also show that this result extends to a composite measure of WMC based on three different complex span tasks. Therefore, the observed lack of relationship is not specific to operation span, but to WMC in general.

As seen through the prism of the widely accepted executive attention view, WMC consists of the ability to use attention to maintain task-relevant information active in memory and to inhibit interfering information (Engle, 2002; Kane et al., 2004). Therefore, the fact that the categorical deviation effect is unrelated to working memory abilities represents further evidence that this auditory distraction phenomenon cannot be modulated by attentional control (see also Vachon et al., 2020). The immunity of the categorical deviation effect to top-down influences differentiates it from its acoustic analog, which is known to be modulated by cognitive control (e.g., Hughes et al., 2013; Marsh et al., 2020; for a review, see Sörqvist & Marsh, 2015). While there is consensus that the acoustic deviation effect can be explained in terms of attentional capture (e.g., Escera et al., 2003; Hughes et al., 2005, 2007; Lange, 2005; Marois et al., 2019; Parmentier, 2008; Vachon et al., 2017), our findings suggest that a different process may be at the origin of the disruption caused by a categorical deviation. In the next section, we delve into arguments both in favor and against the attentional origin of the categorical deviation effect before turning to other potential mechanisms that could underpin this phenomenon.

Examination of the hypothesis of an attentional origin

Prior to exploring the possibility that the categorical deviation effect is underpinned by attentional mechanisms (like its acoustic counterpart), the processes typically used to explain the occurrence of the acoustic deviation effect must be further detailed. An acoustically deviating sound is deemed to capture attention when it violates expectations about incoming auditory stimulations that are generated automatically by the cognitive system. These expectations are derived from a neural model (cf. Sokolov, 1963), which consists of a predictive mnemonic representation of the acoustic regularities that characterized the recent auditory past (e.g., Bendixen et al., 2007; Hughes et al., 2007; Marois et al., 2020; Parmentier et al., 2011; Schröger, 1997; Vachon et al., 2012; Winkler et al., 2009). Some authors assert that only the physical properties of the sound are represented in the neural model (e.g., Cowan, 1995, Sokolov, 1963). Therefore, by not being included, the semantic properties of the sound would be unable to capture attention. Yet, researchers have recently argued that even the semantic content of unattended sound may be processed automatically (e.g., Marsh et al., 2014; Vachon et al., 2020). Following this logic, it remains plausible that the occurrence of a categorical deviant could break neural model-based expectations and thus capture attention, just like the occurrence of an acoustic deviant.

Some support for the hypothesis that the categorical deviation effect could reflect a form of attentional capture comes from studies on the relationship between WMC and visual deviance distraction. Although WMC is generally related to the ability to avoid visual distracters or to recover faster from distraction (Fukuda & Vogel, 2009, 2011), Robison and Unsworth (2017) have shown that attentional capture by a visual deviant does not always correlate with WMC. In the specific settings where they observed such a lack of relationship, participants were asked to search for a white visual target with a unique shape among other white items. In half of the trials, one of the nontarget items was of a different color than the rest of the set, but this distinct color was irrelevant to the task. The authors attribute the absence of relationship between WMC and the disruption engendered by this color singleton to the latter's uniqueness. Indeed, given the specific task instructions (i.e., search for a unique shape), the distractor might have been briefly considered as potentially relevant because it was particularly salient.

A parallel can be made between Robison and Unsworth's (2017) study and the current investigation. In both our experiments, the category from which either the deviant or the standard sounds were taken was the same as the category representing the TBR items. Therefore, it remains possible that this relationship between visual and auditory items made any categorical change seem particularly relevant to the participants, which abolished the relationship between WMC and susceptibility to attentional capture by the deviant. It should nevertheless be kept in mind that Robison and Unsworth's results were obtained in the context of a visual search task, wherein the identity of the target stimulus is arguably much more important than in a serial recall task. Indeed, in serial recall, the focus is on the relative position of the TBR items rather than on their identity (e.g., Beaman & Jones, 1997; Buschke, 1963; Jones et al., 2004; Murdock, 1993). Although the relationship between the visual and auditory materials used in the current study can be seen as a limitation, it is likely not the cause of the non-significant correlation between the size of the categorical deviation effect and WMC that we observed in both experiments. Indeed, Vachon and colleagues (2020) showed that the categorical deviation effect was of comparable magnitude whether the auditory distractors were related to the visual memoranda or not. The authors also demonstrated that a categorical deviation disrupted serial recall even when the focal task did not promote the activation of semantic codes (e.g., during the serial recall of spatial locations or unfamiliar faces). Therefore, the occurrence of the categorical deviation effect (and arguably its relationship with WMC) is independent of the contingency between TBR and TBI items.

While a number of findings provide strong support for an attentional capture account of the acoustic deviation effect, no such support has so far been offered for the categorical deviation effect. Several studies have shown that being forewarned of an imminent acoustic deviation can reduce or abolish its distracting power (e.g., Hughes et al., 2013; Parmentier & Hebrero, 2013) because of the opportunity to voluntarily integrate the deviant sound into the neural model (cf. Bendixen et al., 2007; Winkler et al., 2009). Therefore, when one is forewarned of the presence of an upcoming deviant sound, the probability of having their attention captured by that sound decreases. Attentional control can also explain the impact of task engagement on the susceptibility to the acoustic deviation effect. Indeed, increasing the degree to which attention is required to perform the focal task (e.g., by increasing the level of task difficulty; Hughes et al., 2013; Marsh et al., 2020) would help attention to remain firmer on the focal task (e.g., Halin et al., 2014; Sörqvist & Marsh, 2015) and mitigate the processing of task-irrelevant sound (e.g., Sörqvist et al., 2016; Sörqvist & Marsh, 2015), hence reducing the likelihood that an acoustically deviant sound captures attention.

Like manipulations that promote the application of cognitive control, WMC can also reduce the impact of acoustically deviant sounds through attentional mechanisms. Individuals with high WMC would be less distracted by an acoustic deviation because of their greater capacity to stay focused on the focal task despite the presence of sounds endowed with the power to capture attention (Conway et al., 2001; Sörqvist et al., 2013). Together, the findings pertaining to foreknowledge, task-engagement, and WMC all support an attentional capture account of the acoustic deviation effect. However, based on the current study as well as on other investigations (Littlefair et al., this volume; Vachon et al., 2020), the same cannot be said for the categorical deviation effect. As mentioned in the Introduction, Vachon and colleagues (2020) examined whether top-down manipulations that are known to modulate disruption caused by an acoustic deviation had a similar influence on that caused by categorical deviants. More specifically, in one of their experiments (Exp. 5), the authors warned the participants whenever the auditory stimulation they were about to hear in the next trial included a deviant sound. In addition to providing this unspecific warning, they also conducted an experiment (Exp. 7) in which the exact identity of the deviant item was revealed (e.g., the specific digit that would be inserted in the sequence of TBI letters). The researchers also examined whether promoting focal-task engagement by decreasing the discriminability of TBR stimuli would decrease the size of the categorical deviation effect, not only as a single manipulation (Exp. 4) but also in combination with deviant foreknowledge (Exp. 6). In all four experiments described here, the disruption caused by a categorical deviation was not diminished compared to a condition in which no specific measures were taken to try to decrease the distracting impact of the deviant sound. Overall, our results and those of Vachon and colleagues (2020) strongly suggest that the behavioral manifestation of the disturbance caused by a change in category within the auditory background is independent from attentional control. Indeed, since WMC is deemed to reflect the ability to maintain relevant information active for processing despite the presence of interfering information (Engle, 2002; Kane et al., 2004), our observation that the categorical deviation effect is not tempered by WMC also implies that it is immune to cognitive control.

Finally, if both the acoustic and the categorical deviation effects shared a similar origin, a positive correlation between the size of these two effects would have been expected in Experiment 2. Instead, we found no relationship between these two effects, further suggesting that the categorical deviation effect is not dependent upon participants' susceptibility to attentional capture. Our results suggest that the disruption caused by a categorical deviation is subtended by different mechanisms than those responsible for the disruption caused by an acoustic deviation. Therefore, we come to the conclusion that the categorical deviation effect does not have an attentional origin (see also Littlefair et al., this volume).

Exploration of other potential explanations

If not attentional capture, what mechanism could underpin the categorical deviation effect? The first candidate we investigate in our attempt to answer this important question is the interference-by-process mechanism. Interference-by-process is a well-established form of auditory distraction that is particularly relevant here as it has been shown to be unrelated to WMC (Hughes et al., 2013; Sörqvist, 2010; Sörqvist et al., 2013). It represents the disruption caused when the involuntary processing of the background sound interferes with the deliberate processing involved in the execution of a cognitive task (see Hughes, 2014). In the case of a serial recall task, which requires the processing of the order of the TBR items, the typical manifestation of interference-by-process is referred to as the changing-state effect. The latter can be observed when serial recall is performed concurrently with the presentation of a sequence of changing spoken items (e.g., B-H-F-K-M-R-X-Q in comparison to repetitive sounds such as B-B-B-B-B-B-B-B). In such conditions, the cognitive system automatically attempts to seriate the auditory distractors (e.g., Beaman & Jones, 1997; Hughes & Marsh, 2020; Jones & Macken, 1993; Jones & Tremblay, 2000; Marois et al., 2019), which hinders the rehearsal of the serial order of the relevant TBR items. However, although we used a serial recall task in both experiments of the current study, the changing-state effect can likely not be considered as a plausible explanation for our results. Indeed, auditory sequences were acoustically changing in all trials, whether standard or deviant. Therefore, the changing-state effect cannot be used to explain the occurrence of the categorical deviation effect or its (lack of) relationship with WMC.

Interference-by-process can also manifest itself in the form of the between-sequence semantic similarity effect (e.g., Beaman, 2004; Hanczaowski et al., 2017; Marsh et al., 2008, 2009, 2015). This type of auditory distraction takes place when the automatic processing of the semantic content of the irrelevant sound impairs performance of the focal task because the latter requires processing the meaning of semantically related relevant items (e.g., in the case of a free recall task; see Marsh & Jones, 2010). Even though the meaning of the irrelevant sound has presumably been processed automatically for the categorical deviation effect to occur in the present study, such processing was likely not essential to perform the serial recall of the visual digits. Indeed, to carry out a serial recall task successfully, the relative position of the TBR items matters more than their individual meaning (e.g., Beaman & Jones, 1997; Buschke, 1963; Jones et al., 2004; Murdock, 1993). In addition, the categorical deviation effect has been shown to occur independently of the processes involved in the focal task and the type of materials employed as TBR and TBI items (Vachon et al., 2020). Therefore, as with attentional capture, there seems to be too many inconsistencies to be able to conclude that the categorical deviation effect is subtended by an interference-by-process mechanism.

Because neither attentional capture nor interference-by-process appear to be at the origin of the categorical deviation effect, the latter casts some doubt on the ability of the most prevalent theories (i.e., the duplex-mechanism account; Hughes, 2014; Hughes et al., 2007; and the unitary, attention-capture account; e.g., Cowan, 1995; Bell et al., 2019, 2021; Körner et al., 2017) to fully explain all existing forms of auditory distraction. We believe it would be unadvised at this time to comment on whether and how these theories could be modified to explain the categorical deviation effect since little is yet known about this phenomenon. Nonetheless, while this proposition may seem to lack parsimony, it remains possible that a novel auditory distraction mechanism would be needed to account for the disruption caused by categorical deviants. Together, the findings from the current study as well as those of Vachon et al. (2020) and Littlefair et al. (this volume) suggest that the mechanism underlying the categorical deviation effect could be specific to the automatic processing of the semantic content of the auditory background, irrespective of the processes engaged in the disrupted task. An auditory distraction phenomenon similar to the one we describe here has also been reported by Röer, Bell, and colleagues (2019). More precisely, these researchers discovered the semantic mismatch effect, whereby a word presented at the end of a sentence disrupts performance on a cognitive task when that word is semantically unexpected based on the context of the sentence. The authors showed that the effect was not subject to habituation (Röer, Bell, et al., 2019, in press; Röer, Buchner, & Bell, 2019), which contrasts with evidence-based expectations of an attenuation of the attention-capturing power of deviant sounds over time (e.g., Marois et al., 2018; Vachon et al., 2012). Likewise, a recent study shows no evidence of habituation of the behavioral response to categorical deviations (Littlefair et al., this volume). In both the categorical deviation and the semantic mismatch effects, the distracting power of the mismatching item is not attributable to its individual meaning (compared to, for instance, the disruption that would be caused by taboo words or one's own name; Röer et al., 2013, 2017). Rather, the perturbation they cause is due to a violation of the expectations derived from the semantic content of irrelevant sound. Despite this resemblance, there is no guarantee that these two phenomena share a common origin. Indeed, in investigations about the semantic mismatch effect, the irrelevant speech is presented in the form of complete sentences. In studies about the categorical deviation effect, the semantic content of the irrelevant speech is not as rich; the auditory stream is solely composed of individual items generally taken from a single semantic category. The content of linguistically meaningful sentences may therefore prove to be particularly interesting for participants, which could make it more likely to divert attention than individual speech tokens (see Hughes & Marsh, 2020). Future research comparing susceptibility to the categorical deviation and semantic mismatch effects will likely help determine whether they share a common origin.

Limitations

Despite its strength in showing for the first time (and in two different experiments) that the categorical deviation effect is not related to WMC, some limitations of the current study must be acknowledged. First, both Experiments 1 and 2 had relatively small sample sizes for correlational purposes, which could have impacted the accuracy of the obtained correlations

(Schönbrodt & Perugini, 2013). Although the combination of the two experiments provides additional support for the hypothesis of a lack of relationship between WMC and the size of the categorical deviation effect, we cannot completely rule out the possibility that there is a small, yet true relationship between these variables that our analyses were simply not powerful enough to detect. Furthermore, in both experiments of the present investigation, some participants achieved the maximum scores on the tasks designed to measure WMC (although no participant achieved the maximum score on all three tasks used in Experiment 2). Thus, it remains possible that stronger relations between the variables of interest would have emerged without this potential ceiling effect. The use of difference measures (i.e., difference in performance between standard and deviant trials) is another limitation given these type of measures can be unreliable, especially when calculated from only a small number of trials (Ellermeier & Zimmer, 1997; see Körner et al., 2017, for further discussion of the limitations of difference measures). However, due to the need to keep the deviant sound unpredictable to avoid habituation effects, we argue that having a small number of deviant trials is an inevitable consequence of the study of deviance distraction.

Future directions

More work is undoubtedly needed to fully characterize the categorical deviation effect and understand the processes underlying it. Examining the relationship between the size of the categorical deviation effect and performance on tests assessing different abilities involved in speech processing (from auditory discrimination to syntactic and semantic capabilities) could help determine which language mechanisms underlie this phenomenon, if any. Since the left brain hemisphere has been shown to specialize in the semantic processing of speech (see, e.g., Zahn et al., 2000), future studies could also examine whether there exist lateral asymmetries in the manifestation of the categorical deviation effect. If this phenomenon stems from language processing, the disruption caused by a categorical deviation should be more pronounced when sound streams comprising a categorical deviant are presented to the right ear, and therefore enter the left hemisphere (cf. Sörqvist et al., 2010). The use of psychophysiological measurement techniques such as electroencephalography and pupillometry could also help better understand the categorical deviation effect. More precisely, the examination of N400 and P600 event-related potentials would be particularly relevant as they are both related to the presence of semantic irregularities (Kutas & Federmeier, 2011; van Herten et al., 2005). Finally, future research could compare the pupillary response to acoustic and categorical deviations, as attentional capture by acoustic deviations has been shown to be indexed by pupillary dilation (e.g., Marois et al., 2018, 2019, 2020; Marois & Vachon, 2018; Zhao et al., 2019). Pupil size has also been demonstrated to relate to semantic effects in the auditory domain (see Zekveld et al., 2018), making it an interesting candidate to be used in further examination of the difference between the acoustic and categorical deviation effects.

Conclusion

On the surface, the categorical and acoustic deviation effects share many similarities. However, by showing that the categorical deviation effect is unrelated to WMC, the current study adds to recent evidence that this effect is independent of cognitive control, in sharp contrast with its acoustic counterpart. While our results indicate that the acoustic and categorical deviation effects are subtended by distinct mechanisms, we cannot yet provide a definitive explanation as to the processes underlying the latter. We nevertheless suggest potential avenues that can be taken to continue investigating the origin of this effect.

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Declaration of interest statement

The authors have no conflict of interest to disclose.

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Tables

Table 1

Summary (mean and SD*) of measures related to the magnitude of the deviation effects and to working memory capacity of Experiment 2*

Measure	***M***	***SD***
Acoustic deviation effect size (in %)	6.28	6.87
Categorical deviation effect size (in %)	5.98	7.24
Operation span score (max = 25)	16.53	6.73
Rotation span score (max = 14)	6.76	3.72
Symmetry span score (max = 14)	6.91	3.73
Composite score (in %)	54.60	19.24

Note. The size of each deviation effect represents the difference between mean serial recall performance on all standard trials and mean serial recall performance on all acoustic deviant and categorical deviant trials, respectively (in %).

Table 2

Pearson correlations between the size of the acoustic and categorical deviation effects and measures related to working memory capacity of Experiment 2 (and associated Bayes factors)

	Acoustic deviation	Categorical deviation	Operation span	Rotation span	Symmetry span
Categorical deviation	.018 (10.374)[a]	–			
Operation span	-.320** (0.312)[e]	-.105 (7.299)[b]	–		
Rotation span	.045 (9.802)[b]	-.066 (9.082)[b]	.270* (0.891)[d]	–	
Symmetry span	-.283* (0.693)[d]	-.092 (7.941)[b]	.275* (0.805)[d]	.294* (0.554)[d]	–
Composite score	-.259* (1.100)[c]	-.122 (6.433)[b]	.717** (6.43×10^{-10})[f]	.721** (4.34×10^{-10})[f]	.724** (3.22×10^{-10})[f]

**p* < .05. ***p* < .01.
[a] Strong evidence for H_0. [b] Moderate evidence for H_0. [c] Anecdotal evidence for H_0. [d] Anecdotal evidence against H_0.
[e] Moderate evidence against H_0. [f] Extreme evidence against H_0.

Figures

Figure 1

Results from Experiment 1: Mean percentage of digits correctly recalled in standard and deviant trials. Error bars represent the standard error of the mean.

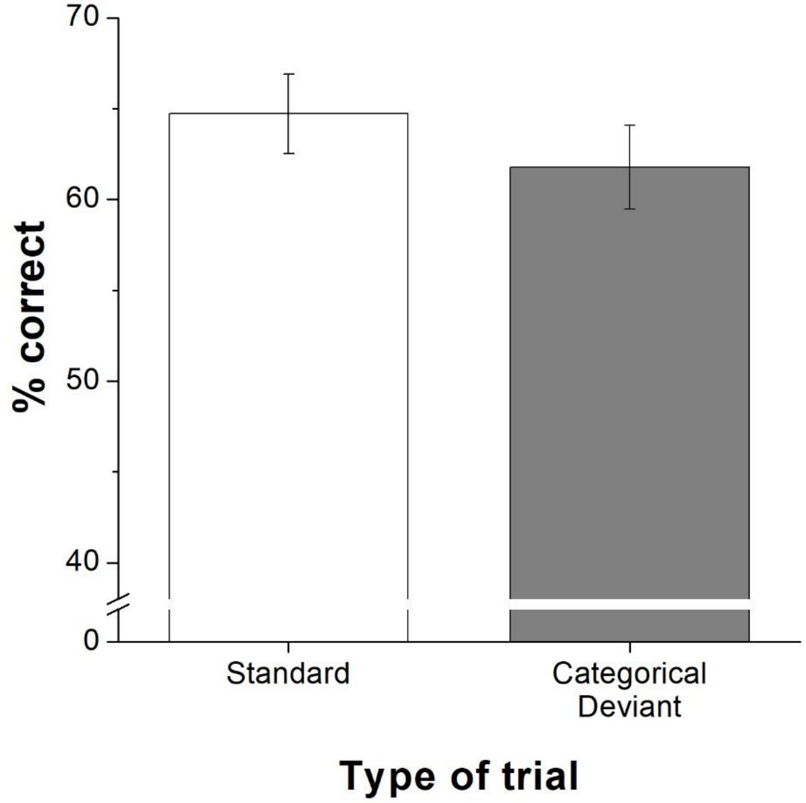
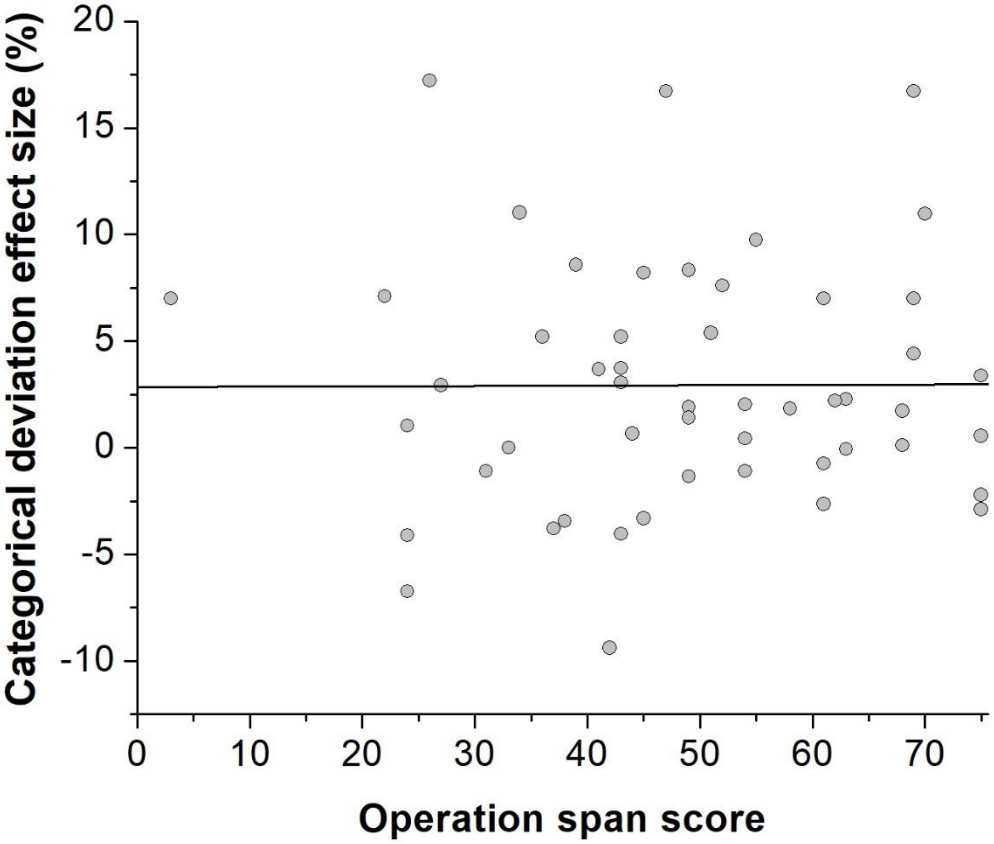


Figure 2

Results from Experiment 1: Size of the categorical deviation effect plotted against the operation span score.



Note. The size of the categorical deviation effect represents the difference between mean serial recall performance on all standard trials and mean serial recall performance on all categorical deviant trials (in %).

Figure 3

Results from Experiment 2: Mean percentage of digits correctly recalled in the three types of trials. Error bars represent the standard error of the mean.

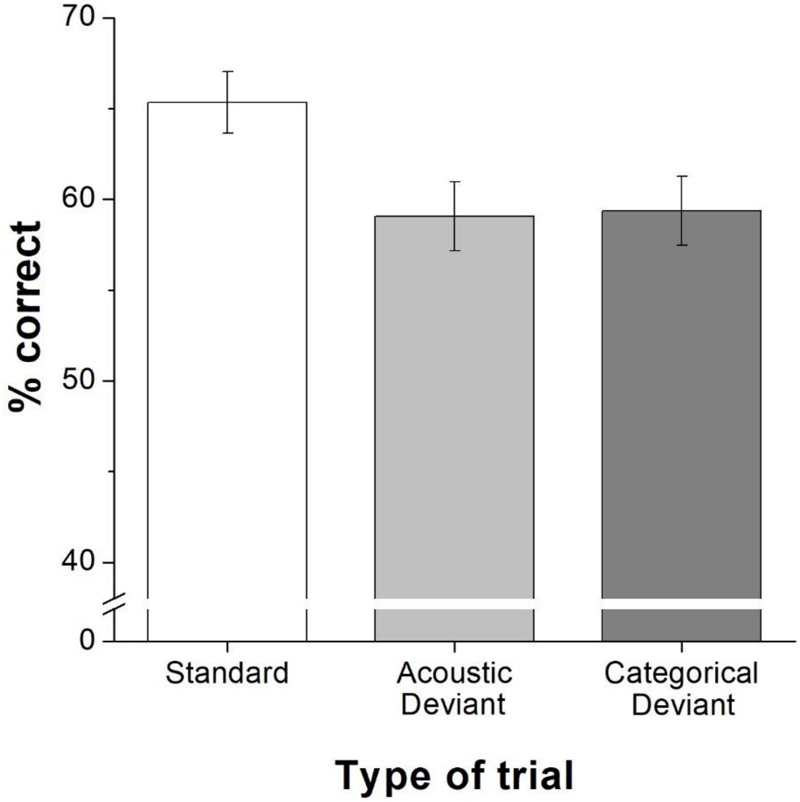
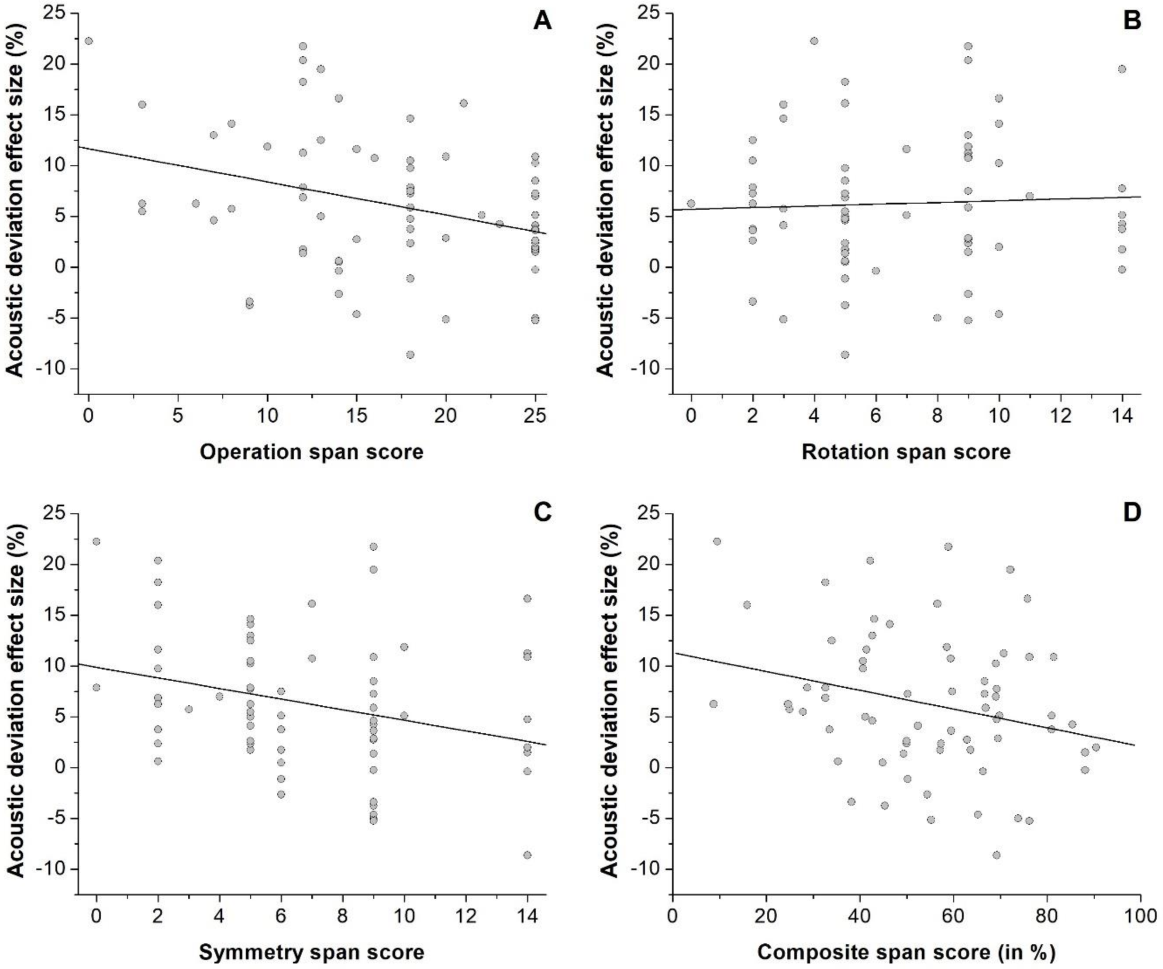


Figure 4

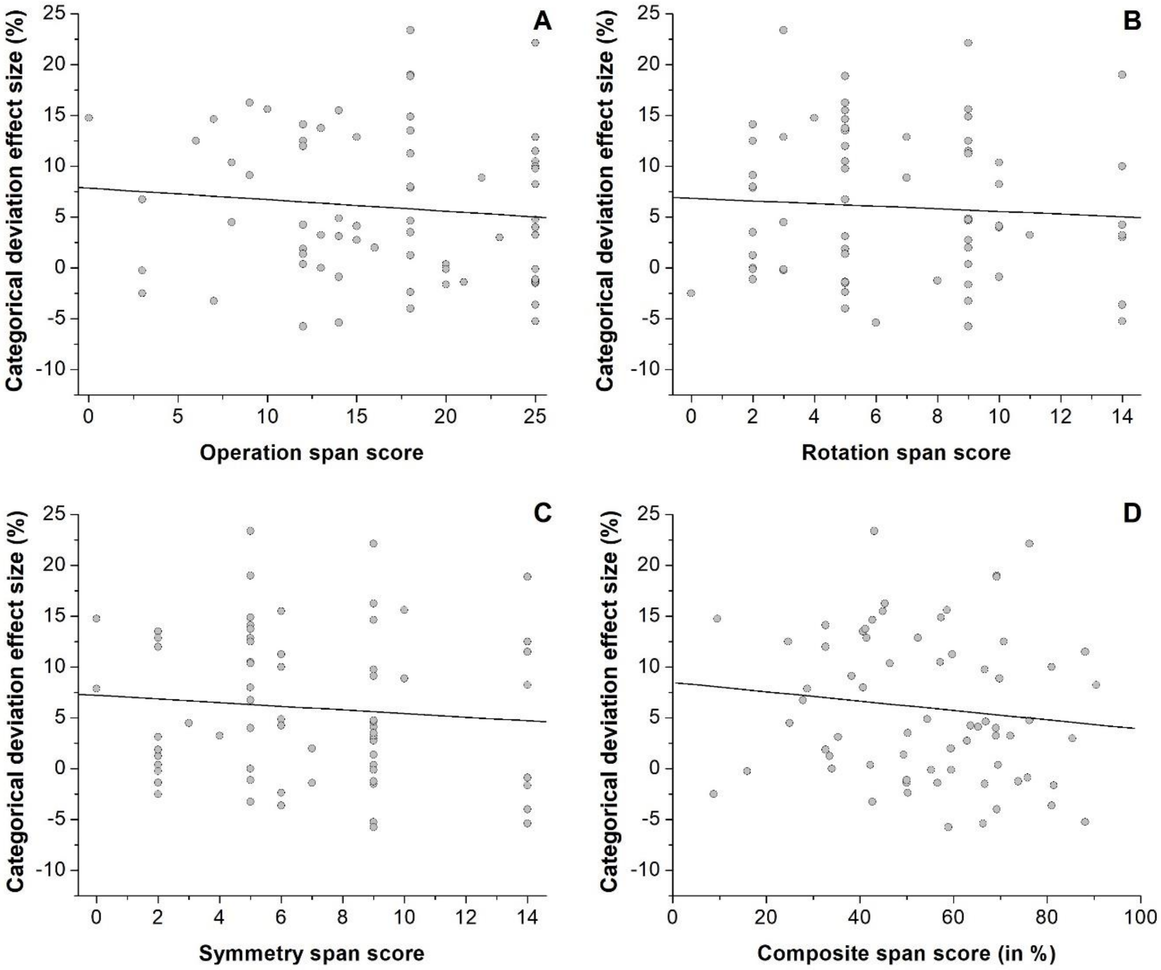
Results from Experiment 2: Magnitude of the acoustical deviation effect plotted against the operation span score (A), the rotation span score (B), the symmetry span score (C) and the composite span score (D).



Note. The size of the acoustic deviation effect represents the difference between mean serial recall performance on all standard trials and mean serial recall performance on all acoustic deviant trials (in %).

Figure 5

Results from Experiment 2: Magnitude of the categorical deviation effect plotted against the operation span score (A), the rotation span score (B), the symmetry span score (C), and the composite span score (D).



Note. The size of the categorical deviation effect represents the difference between mean serial recall performance on all standard trials and mean serial recall performance on all categorical deviant trials (in %).