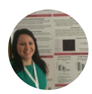
Attentional Capture by Deviant Sounds: A Non-Contingent Form of Auditory Distraction?

Article *in* Journal of Experimental Psychology Learning Memory and Cognition · July 2016

3 authors:

François Vachon
Laval University



Katherine Labonté
Laval University

John E Marsh
University of Central Lancashire

This manuscript has been accepted for publication in *Journal of Experimental Psychology: Learning, Memory, and Cognition* on July 18, 2016.

Attentional Capture by Deviant Sounds: A Non-Contingent Form of Auditory Distraction?

François Vachon[1], Katherine Labonté[1], & John E. Marsh[2,3]

[1]École de psychologie, Université Laval, Québec, Canada

[2]School of Psychology, University of Central Lancashire, Preston, UK

[3]Department of Building, Energy, and Environmental Engineering, University of Gävle, Gävle, Sweden.

Author Note

This research received financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC) in the form of a grant awarded to François Vachon and in the form of a scholarship awarded to Katherine Labonté. Correspondence concerning this article may be addressed to François Vachon, École de psychologie, Université Laval, Québec (QC), G1V 0A6, Canada. E-mail: francois.vachon@psy.ulaval.ca.

Abstract

The occurrence of an unexpected, infrequent sound in an otherwise homogeneous auditory background tends to disrupt the ongoing cognitive task. This 'deviation effect' is typically explained in terms of attentional capture whereby the deviant sound draws attention away from the focal activity, regardless of the nature of this activity. Yet, there is theoretical and empirical evidence suggesting that the attention-capture mechanism underlying this form of distraction could rather be triggered in a task-contingent fashion. The present study aimed at determining whether the auditory deviation effect reflects the action of either a stimulus-driven or a task-contingent orienting mechanism. To do so, we conducted a systematic investigation whereby the impact of verbal deviants—a letter embedded in the repetition of another letter—and spatial deviants—a sound presented contralaterally to the other sounds—on verbal and spatial short-term memory was assessed. This study established that both verbal and spatial deviants can hinder both verbal and spatial order-reconstruction (Experiment 1) and missing-item tasks (Experiment 2). Such results demonstrate that the deviation effect reflects a general form of auditory distraction as interference took place both within and across domains and regardless of the processes engaged in the focal task.

Keywords: auditory distraction; attentional capture; auditory deviation; cross-domain interference; task set.

Attentional Capture by Deviant Sounds: A Non-Contingent Form of Auditory Distraction?

The execution of ongoing cognitive activity can be disrupted by the occurrence of events that are not directly relevant to current behavioral goals. Such distractibility is classically explained in terms of attentional capture whereby unattended stimuli involuntarily direct attention away from goal-relevant information by virtue of their strong contrast with the environmental background. There is a debate in the visual attention literature regarding the source of this attentional capture phenomenon (see Theeuwes, Olivers, & Belopolsky, 2010). One hypothesis is that the attention-grabbing effect of an unexpected or distinctive stimulus is independent of the internal mental state of the individual (e.g., Jonides, 1981; Theeuwes, 1994; Yantis & Jonides, 1990). However, it is also possible that some stimuli attract attention because of their potential behavioral relevance, such as when they share attributes or features with the stimuli the person is actively processing. There is in fact evidence that attentional capture can be contingent on the attentional set (i.e. the individual’s current intentions, goals, expectations) and the task demands (e.g., Belopolsky, Schreij, & Theeuwes, 2010; Eimer & Kiss, 2008; Folk, Remington, & Johnston, 1992). Because the processing of auditory information is largely obligatory, behavior is particularly vulnerable to distraction by sound (see, e.g., Dalton & Hughes, 2014; Hughes & Jones, 2003). The present study addressed this controversy within the auditory domain by examining whether attentional capture by auditory deviation—i.e. an auditory event that deviates in some way from the recent auditory past—reflects the action of either a stimulus-driven or a task-contingent orienting mechanism.

Recent evidence suggests that human performance is susceptible to auditory distraction in, at least, two functionally distinct ways. According to the duplex-mechanism account of auditory distraction (Hughes, Vachon, & Jones, 2005, 2007; see also Hughes, 2014), irrelevant sound can cause undesired distraction either by interfering specifically with the processes engaged in the ongoing task (interference-by-process) or by temporarily disengaging attention from the focal activity (attentional capture). Beyond the empirical demonstrations of the existence of two distinct forms of auditory distraction (e.g., Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013; Hughes et al., 2005, 2007; Sörqvist, 2010; Sörqvist, Marsh, & Nöstl, 2013; see also Marsh, Sörqvist, & Hughes, 2015), these two distraction mechanisms can be distinguished at the theoretical level on the basis of whether their action depends on the type of relevant and irrelevant stimuli used and on the nature of the task.

Interference-by-process can be viewed as a contingent form of distraction as it is assumed to result from a conflict between the involuntary processing of the sound and the deliberate processing deployed to perform the focal task (e.g., Jones & Macken, 1993; Jones & Tremblay, 2000; Marsh, Hughes, & Jones, 2009). A key auditory distraction phenomenon that has traditionally been ascribed to the interference-by-process mechanism is the changing-state effect, that is, the disruption of visual short-term serial memory by to-be-ignored (TBI) sound that is changing acoustically (Colle & Welsh, 1976; Jones & Macken, 1993; Jones, Madden, & Miles, 1992; Salamé & Baddeley, 1982). It has been argued that this effect is best explained by a conflict—or competition for action—between two processes involving the maintenance of the order of events: Obligatory perception of changes in a changing-state auditory sequence yields information about order which competes for, and hence hinders, the deliberate, goal-driven process of rehearsing the to-be-remembered (TBR) items in serial order (e.g., Hughes, Tremblay, & Jones, 2005; Jones & Macken, 1993; Jones & Tremblay, 2000). When serial rehearsal is a negligible aspect in the focal task, changing-state sound is no more disruptive than steady-state sound (e.g., Beaman & Jones, 1997; Hughes et al., 2007). The same interference-by-process mechanism has been also invoked to account for the disruption of a visual focal task requiring semantic (e.g., Jones, Marsh, & Hughes, 2012; Marsh, Hughes, & Jones, 2008, 2009) or phonological processing (Marsh, Vachon, & Jones, 2008) by the concurrent presentation of irrelevant sound that is semantically or phonologically related, respectively, to the TBR material (see Marsh & Jones, 2010, for a review).

In stark contrast with interference-by-process, the attentional-capture mechanism—which is the focus of the present study—is assumed to reflect a general form of auditory distraction, dragging attention away from the focal task “regardless of the type of processing that task involves” (Hughes, 2014, p. 30). Attentional orienting to auditory stimuli has been demonstrated mainly using the deviant (or oddball) paradigm in which, a rare, unexpected sound deviates from the auditory context in which it is embedded. On this account, attentional capture occurs when an auditory event violates—i.e. deviates from—the neuronal model (cf. Sokolov, 1963), an abstract predictive representation based on any invariance governing the organization of the auditory stimulation (e.g., Hughes et al., 2005, 2007; Parmentier, Elsley, Andrés, & Barceló, 2011; Schröger, 1997; Schröger, Bendixen, Trujillo-Barreto, & Roeber, 2007; Vachon, Hughes, & Jones, 2012; Winkler, Denham, & Nelken, 2009). Various forms of auditory deviation have been shown to slow down response times (e.g., Escera, Alho, Winkler, & Näätänen, 1998; Parmentier, Elford, Escera, Andrés, & San Miguel, 2008; Schröger & Wolff, 1998) or degrade accuracy on a visual focal task (e.g., Lange, 2005; Hughes et al., 2007; Vachon et al., 2012), from an acoustical (e.g., Lange, 2005; Sörqvist, 2010; Vachon et al., 2012) or temporal irregularity (e.g., Hughes et al., 2005) to a deviation from a sound pattern (e.g., Hughes et al., 2007; Marsh, Röer, Bell, & Buchner, 2014; Nöstl, Marsh, & Sörqvist, 2012, 2014).

The attentional-capture mechanism underlying the deviation effect is thought to be independent of both task requirements and the relation between relevant and irrelevant materials because different types of verbal and non-verbal deviant stimuli are known to disrupt performance of a range of focal visual tasks, such as verbal serial recall (e.g., Lange, 2005; Hughes et al., 2005, 2007; Marsh, Vachon, & Sörqvist, in press; Sörqvist, 2010; Vachon et al., 2012), the missing-item task (e.g., Hughes et al., 2007), or speeded discrimination judgments (e.g., Escera et al., 1998; Nöstl et al., 2012; Parmentier et al., 2008; Schröger & Wolff, 1998). Even though this assumption that attentional capture by deviant sounds reflects a purely non-contingent phenomenon is central to the duplex-mechanism account (cf. Hughes, 2014) and widely accepted (see, e.g., Cowan, 1995), there is theoretical and empirical evidence suggesting that the attention-capture mechanism underlying this form of distraction could rather be triggered in a task-contingent fashion.

The deviation effect is most commonly explained through the preattentive fabrication of a short-term representation of the recent auditory past (e.g. Cowan, 1995; Schröger, 1997). This so-called neuronal model (Sokolov, 1963) is an abstract forward (or predictive) record derived from the acoustical regularities embodied in the unfolding auditory stimulation (e.g., Hughes et al., 2007; Parmentier et al., 2011; Vachon et al., 2012; Winkler et al., 2009). An implicit process compares the sensory representation of the current sound to the predictions generated by the neuronal model. If a discrepancy (or deviation) is detected between the representation of the actual sound and the implicit expectancies derived from the neuronal model, a mismatch signal is generated. This ‘call for attention’ is assumed to be proportional to the amount of the difference between the two representations (Schröger, 1997). An involuntary shift of attention toward the deviant sound is triggered—i.e. the call is answered—only if the mismatch signal exceeds a certain threshold. This threshold is assumed to be variable and modulated by the attentional set, the available attentional resources and “the channel separation of task-relevant and task-irrelevant aspects of stimulation” (Schröger, 1997, p. 253). This suggests that when performing, for instance, a verbal task (in which spatial information remains constant), the threshold should be set low for goal-relevant verbal features to promote their processing but high for (goal-irrelevant) spatial characteristics, to protect the cognitive system against distraction. In such a case, the signal produced by a deviation of verbal nature is more likely to exceed the threshold and evoke an orienting response than the signal provoked by a spatial deviation. The opposite pattern would apply in the context of spatial task. Such modulation of the mismatch-detection threshold implies that the attention-capture mechanism underlying the deviation effect is task-contingent in nature, contrary to what posits the duplex-mechanism account.

At the empirical level, two lines of evidence failed to find support for a non-contingent mechanism. For instance, Lange (2005) conducted four experiments on the deviation effect that compared the effects of auditory and visual distractors on visually-presented short-term memory (STM) tasks, and thus, compared domain-specific and non-specific effects of attention. She found that an auditory irrelevant tone (i.e. non-verbal) change disrupted performance on verbal, but not spatial, serial recall tasks, whereas a sudden change presented in the irrelevant *visual*-spatial stimuli hampered recall for the spatial, but not the verbal task. Such a pattern of results led Lange to conclude that the deviation effect reflects a domain-specific distraction phenomenon, hence arguing against the assumption of the duplex-mechanism account of auditory distraction that attentional capture is a general form of distraction.

Notwithstanding the numerous demonstrations that various types of auditory deviants can disrupt the execution of a wide range of visual and auditory tasks, recent work on the deviation effect also provided evidence that calls into question the non-contingent nature of the phenomenon postulated in the duplex-mechanism account. Indeed, it has been shown that behavioral distraction by deviant sounds occurs exclusively when standard sounds carry information about the likelihood of occurrence of an upcoming target (e.g., Li, Parmentier, & Zhang, 2013; Ljungberg, Parmentier, Leiva, & Vega, 2012; Parmentier, Elsley, & Ljungberg, 2010; Wetzel, Schröger, & Widmann, 2013; Wetzel, Widmann, & Schröger, 2012). For example, Ljungberg et al. (2012) observed distraction only in conditions in which the auditory distractor announces with certainty the imminent presentation of a visual target. Such findings indicate that the auditory deviation effect takes place only when the irrelevant sound conveys goal-directed information and, hence, suggest that this form of auditory distraction is underpinned by a task-contingent mechanism.

Present Study

Given the dissention in the literature about the specific nature of the auditory deviation effect, the present study aimed to determine whether this phenomenon reflects the action of either a generic or a task-contingent orienting mechanism. To do so, we performed a systematic comparison of the impact of a verbal and a spatial auditory deviation on the performance on verbal and spatial visual STM tasks. Because the across-domain comparison was central to the present research question, great care was taken at equating the procedure across the verbal and the spatial domains. Accordingly, both verbal and spatial versions of the task tapped onto the same processing requirements (e.g., required order reconstruction), and involved matched stimulus presentations (e.g., same presentation rate, same timings of the TBR items and ISIs and the same number of TBR and TBI items [Experiment 1A and 1B]). The task consisted of the sequential presentation of a list of TBR visual stimuli. In the verbal version, the list was comprised of a closed set of digits appearing at the center of the screen whereas in the spatial version, stimuli consisted of non-verbal items (dots) displayed in a restricted set of different spatial locations. While the visual stimulus presentation was kept constant across experiments for both verbal and spatial material, we employed two different tasks in order to further establish that the deviation effect does not rely on task requirements. Hence, participants were told either to recall the items in their order of presentation (Experiment 1) or to identify which item was missing from the stimulus set (Experiment 2). Each visual list was accompanied by the concurrent presentation of a TBI auditory sequence composed of the repetition of the same randomly chosen letter. On rare trials, the sequence contained a sound that deviated from the rest of the auditory stimuli. In the verbal deviant condition, the deviation consisted of a change in letter identity (e.g., AAAAABAA) whereas in the spatial deviant condition, the deviation corresponded to a change in stimulus location (the repeated letter was presented to the ear contralateral to the rest of the auditory sequence).

Our 2 (task: verbal vs. spatial) × 2 (deviation: verbal vs. spatial) experimental design allowed to test whether verbal deviations (Experiments 1A and 2A) and spatial deviations (Experiments 1B and 2B) are endowed with the power to disrupt verbal and spatial STM. Embracing a non-contingent view of auditory attentional capture (e.g., Hughes et al., 2007), the dual-mechanism account of auditory distraction predicts a cross-domain deviation effect: Performance should be disrupted in deviant trials regardless of the nature of the task—including stimulus domain and task requirements—or of the deviation. On the other hand, if auditory attentional capture reflects a contingent form of distraction (e.g., Lange, 2005; Ljungberg et al., 2012; Schröger, 1997; Wetzel et al., 2013), disruption should arise when the nature of the deviation matches that of the task. Hence, verbal STM should be disrupted by the occurrence of a verbal deviation while spatial STM should be impaired when a spatial deviant is presented.

Experiment 1

The first experiment sought to demonstrate that both a verbal and a spatial deviation within an irrelevant auditory stream can disrupt both visual-verbal and visual-spatial STM tasks. More specifically, the task to be performed was order reconstruction, in which seven items taken from a closed set were presented sequentially on a screen. For recall, all items reappeared simultaneously on the screen and participants had to click on them in their order of presentation.

In verbal reconstruction, lists were composed of seven digits whereas sequences consisted of seven spatially distributed dots in spatial reconstruction. Such a procedure has been shown to allow a direct comparison between the verbal and the spatial domains (e.g., Guérard & Tremblay, 2008; Jones, Farrand, Stuart, & Morris, 1995).

Participants performed both verbal and spatial versions of the order reconstruction task but experienced only one type of auditory deviation. The impact of verbal deviation was tested in Experiment 1A, in which deviant sounds consisted of an unexpected change in spoken letter identity. The effect of spatial deviations, which corresponded to a change in stimulus location, was examined in Experiment 1B.

Method

Participants. Twenty-eight adults (16 women) took part in Experiment 1A while another 35 adults (19 women) participated in Experiment 1B (Experiment 1A was completed before Experiment 1B). All volunteers reported normal or corrected-to-normal vision and normal hearing. They received a small honorarium for their participation.

Materials. The experiment was controlled by a PC computer using E-Prime 2.0 Professional (Psychology Software Tools). TBR visual stimuli were presented on a computer screen located at approximately 60 cm from the participant while TBI auditory stimuli were presented through headphones at approximately 65 dB(A).

TBR visual stimuli. Figure 1 illustrates the type of TBR lists used in the verbal and spatial versions of the serial recall task. The verbal sequences were seven items in length and were taken without replacement from the digit set *1–7* and arranged in a quasi-random order, with the constraint that successive digits were not adjacent integers. Each item was approximately 2.39° in height and presented sequentially in a black Times New Roman font at the center of a white background. The spatial stimuli were sequences of seven black dots of approximately 0.81° in diameter, presented at different locations within a white 16.5° × 16.5° window. Each of these sequences was constructed using a random permutation of the same fixed seven dot locations (see left panel of Figure 2). The centers of any pair of dots were separated by a distance of between 2.86° and 10.07°. In both verbal and spatial sequences, each item was presented for 450 ms and the interstimulus interval (offset to onset) was 400 ms.

Figures 1 and 2 about here

TBI auditory stimuli. Auditory sequences were composed of ten repetitions of the same randomly chosen letter from the letter set *A B C G J K L M Q S* recorded in a female voice. Each letter was spoken at an approximately even pitch and edited using SoundForge software (Sony) so that each lasted 250 ms. The interstimulus interval was 350 ms. For both verbal and spatial recall tasks, the auditory sequence started 125 ms before the TBR sequence (cf. Hughes et al., 2007).

In Experiment 1A, all sounds were presented binaurally. For deviant trials, a different, randomly chosen letter was presented in the 6th position of the sequence, i.e. 125 ms before the onset of the 5th visual item. Thus, the deviant sound corresponded to a change in letter identity, hence a verbal deviant. In Experiment 1B, sounds were presented to a single ear: For half of the participants sounds were presented to the left ear while for the other half, sounds were presented to the right ear. For deviant trials, the 6th letter of the auditory sequence was presented to the ear contralateral to the rest of the auditory stream. Thus, the deviant sound corresponded to a change in stimulus location, hence a spatial deviant. The choice of restricting the presentation of the deviant item to the 6th position of the auditory sequence was motivated by the fact that for the deviant to be potent, a certain buildup—i.e. the presentation of a few stimuli that form some regular pattern—is necessary (e.g., Bendixen, Roeber, & Schröger, 2007; Sams, Alho, &

Näätänen, 1984; Vachon et al., 2012). Previous studies have presented the deviant after five TBI sounds and found reliable deviant effects of substantial magnitude (e.g., Hughes et al., 2005, 2007).

Design. For both Experiments 1A and 1B, the design comprised two repeated-measures factors: Task (verbal or spatial) and Deviation-presence (whether or not the auditory sequence contained a deviation). There were 90 trials in all divided into two blocks: The ‘verbal’ block consisted of 45 trials of verbal serial recall (i.e. the serial recall of digits) and the ‘spatial’ block was comprised of 45 trials of spatial serial recall (i.e. the serial recall of dot locations). The order of the two blocks was counterbalanced across participants. Each block contained 39 ‘without deviant’ trials and 6 ‘with deviant’ trials. In each block, the ‘with deviant’ trials were Trials 5, 8, 18, 27, 35, and 41.

Procedure. At the beginning of each block, participants read standard instructions that informed them of what the serial recall task involved. Hence, participants were told to recall the order of presentation of the seven digits in the ‘verbal’ block whereas they were instructed to recall the seven dots in their order of presentation in the ‘spatial’ block. They were also told that sound would be presented over the headphones but that it was irrelevant to their task and that they were therefore to ignore it. They were not told about the presence of deviant events within the sound.

Each block started with 2 non-deviant practice trials followed by 45 experimental trials. To begin a trial, participants had to press the spacebar. Four hundred milliseconds following the presentation of the seven digits or seven dots, participants had to recall the stimuli. In the verbal task, all digits reappeared horizontally in canonical order, whereas in the spatial task, all dots reappeared in their original location (Figure 1). Participants had to click on the stimuli using the mouse in the order in which they had been presented. Each item turned green once selected. No omissions were allowed. Once participants had recalled the whole sequence, they pressed the spacebar to begin the next trial. Including an optional 5-min break between blocks, the experiment lasted approximately 40 min.

Results

The raw data were scored according to the strict serial recall criterion: To be recorded as correct, an item had to be recalled in its original presentation position. Serial recall performance was submitted to a 2 (Task) × 2 (Deviation-presence) repeated-measures ANOVA in both Experiments 1A and 1B.

Experiment 1A – Verbal deviation. The left panel of Figure 3 presents the percentage of items correctly reported in the four conditions of Experiment 1A: Verbal/No deviant, Verbal/With deviant, Spatial/No deviant, and Spatial/With deviant. The presence of a verbal deviant appeared to be detrimental to both verbal and spatial recall. The ANOVA revealed significant main effect of Task, $F(1, 27) = 14.61$, $p = .001$, $\eta^2 = .351$, recall being better in the verbal task than in the spatial task. Most importantly, the main effect of Deviation-presence was significant, $F(1, 27) = 16.66$, $p < .001$, $\eta^2 = .382$, indicating the presence of a verbal deviation effect. The two-way interaction was not significant, $F(1, 27) = 1.14$, $p = .295$, $\eta^2 = .041$, indicating that the deviation effect was similar for both versions of the task. A Bayes factor analysis on the same data shows that the Bayes factor for the interaction term is 3.98, under the assumption that the r scale parameter is set to 1. A Bayes factor of this size provides positive, but not strong, support for the null-hypothesis.

Figure 3 about here

Experiment 1B – Spatial deviation. The right panel of Figure 3 shows the percentage of items correctly reported in Experiment 1B according to the type of task and the presence or not of a spatial deviant. The pattern of results was similar to that observed in Experiment 1A with a verbal deviation. The ANOVA revealed significant main effect of Task, $F(1, 34) = 27.85$, $p < .001$, $\eta^2 = .450$, showing higher performance in verbal than in spatial serial recall. Most importantly, the main effect of Deviation-presence was significant, $F(1, 34) = 27.35$, $p < .001$, $\eta^2 = .446$, confirming the presence of a spatial deviation effect. As in Experiment 1A, the interaction between Task and Deviation-presence was not significant, $F(1, 34) = 1.73$, $p = .197$, $\eta^2 = .048$, suggesting the size of the deviation effect was similar across tasks. A Bayes factor analysis on the same data shows that the Bayes factor for the interaction term is 3.36, under the assumption that the r scale parameter is set to 1. A Bayes factor of this size yields positive, but not strong, support for the null-hypothesis.

Cross-experiment analysis. To contrast the impact of verbal deviations to that of spatial deviants, results from Experiments 1A and 1B were compared in 2 × 2 × 2 mixed ANOVA with Deviation-type as the between-subjects factor, and Task and Deviation-presence as within-subject factors. The analysis revealed that none of the interactions was significant (ps > .100), indicating that the pattern of results was similar across Experiments 1A and 1B.

Discussion

The results obtained in Experiments 1A and 1B demonstrate that both verbal and spatial deviants incurred a negative cost to both verbal and spatial order reconstruction. Although there is ample evidence for the disruption of verbal STM by auditory deviants (e.g., Hughes et al., 2005, 2007, 2013; Lange, 2005; Sörqvist, 2010; Vachon et al., 2012), we established that spatial STM is also sensitive to attentional capture by unexpected auditory events (see also Marsh et al., in press). The present results also showed that infrequent changes in sound location too have the power to capture attention and impair verbal as well as spatial STM. Previous research has found that such an auditory spatial deviation can elicit a neural index of attentional switching, namely the P3a component of the event-related potentials (e.g., Paavilainen, Karlsson, Reinikainen, & Näätänen, 1989; Winkler, Tervaniemi, Schröger, Wolff, & Näätänen, 1998), and disrupt the processing of sound (e.g., Roeber, Widmann, & Schröger, 2003). Yet, it is, to our knowledge, the first empirical demonstration of cross-modal behavioral distraction effect of an auditory spatial deviation.

The lack of a significant interaction between the type of task and the presence or not of deviation revealed that the effect of the deviant in the verbal task was similar to the effect found in the spatial task. That these factors did not interact with the type of deviation indicated that this was true whether the deviant was verbal or spatial in nature. Such results suggest that the verbal and spatial deviants not only disrupted both tasks, but the deviants' disruptive power also held the same strength for both types of task. This conclusion was supported by the outcome of individual Bayes factor analyses for both experiments which yielded positive evidence for the null-hypothesis, that there is indeed no interaction between the factors of type of task and the presence or not of a deviant as the non-contingent view of auditory attentional capture predicts. Altogether, the present findings provide clear evidence against the contingent view of auditory attentional capture (e.g., Lange, 2005; Schröger, 1997). According to this account, a verbal deviant should have had a larger detrimental impact on verbal than on spatial order reconstruction, whereas an unexpected change of location of the sound should have disrupted memory performance more importantly in the spatial than in the verbal task. Instead, the present results are in line with the predictions of the dual-mechanism account of auditory distraction (Hughes, 2014; Hughes et al., 2005, 2007), which assumes that attentional capture by deviant sounds is a domain-general phenomenon and should take place whatever the relationship between relevant and irrelevant stimuli.

Experiment 2

Experiment 1 established in the context of order reconstruction that impairment of STM processing by auditory deviants is not contingent on an overlap of the properties of relevant and irrelevant stimuli. Such findings are in line with the notion that attentional capture by deviants constitutes a general form of auditory distraction. If the deviation effect is a purely non-contingent phenomenon, then its occurrence should not be dependent on the specific requirements of the focal task. In order to test this hypothesis, we attempted in Experiment 2 to generalize the results of Experiment 1 to a task that does not rely on or encourage serial rehearsal. To do so, we used the missing-item task, which involves presenting all but one of a (typically well-known) set of items (e.g., nine of the ten digits in the set 0–9) in a random order. Subsequently, the participant is required to report the missing item. While this task involves remembering all the items so that the missing item can be identified, it does not necessitate the retention of serial order (Beaman & Jones, 1997; Buschke, 1963; Murdock, 1993). It is well established that some auditory distraction effects, such as the changing-state effect, are dependent on seriation (e.g., Beaman & Jones, 1997). Although it does not appear to be the case for non-spatial deviation effects (Hughes et al., 2007), this has never been tested in the spatial domain. Yet, whether the focal task promoted or not serial processing was trivial here. The key was rather the demonstration that deviation effects can take place regardless of processing requirements.

As in Experiment 1, the impact of the verbal and spatial auditory deviants on the identification of the verbal and spatial missing item was contrasted. The verbal version of the missing-item task was similar to that used by Hughes et al. (2007) which consisted in presenting on each trial a list consisting of 9 digits taken from the 10-digit set 0–9, with the item missing from each list being chosen randomly for each trial. To our knowledge, the missing-item task has never been used in the spatial domain. Because spatial locations forming an arbitrary pattern do not belong to a class of overlearned stimuli such as the digits used in the verbal task, we decided to reduce the spatial stimulus set length from 10 to 9 items (see right panel of Figure 2) to avoid potential floor effects. So, in the spatial version of the task, 8 of the 9 spatial locations were sequentially presented and participants had to report which location, chosen randomly for each trial, was omitted from the list. The auditory stimulations and the verbal and spatial deviations were similar to those used in the previous experiment.

If distraction by auditory deviation is domain-general, the cross-domain distraction found in Experiment 1 should be replicated in Experiment 2. More specifically, the disruptive effect of both types of deviant should apply equally to both versions of the missing-item task even though such tasks do not rely upon serial processing as involved in order reconstruction. If, on the contrary, the deviation effect reflects a contingent form of distraction, disruption of the identification of the missing item will be observed for deviant stimuli from the same domain as the TBR stimuli. Or, at least, the pattern of results should be different from that found in Experiments 1A and 1B due to the change in the focal task.

Method

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

Participants. Sixteen adults (7 women) took part in Experiment 2A while another 22 adults (14 women) participated in Experiment 2B (Experiment 2A was completed before Experiment 2B). All volunteers reported normal or corrected-to-normal vision and normal hearing and received a small honorarium for their participation. None of them took part in Experiment 1.

Materials. The TBR verbal lists consisted of nine items taken without replacement from the 10-item set *0–9*, with the item missing from each list being chosen randomly for each trial. Compared with Experiment 1, the list length was increased by two items because previous evidence suggests that using a list length any shorter than this for the missing-item task—at least when using digits—would likely be too easy and lead to a possible ceiling effect (see Beaman & Jones, 1997). Each digit was presented for 350 ms and was separated from the next one by an interstimulus interval of 300 ms.

In the spatial task, the TBR list was composed of eight black dots presented in different spatial locations. These spatial locations were taken without replacement from the set of nine locations displayed in the right panel of Figure 2, the location missing from each list being chosen randomly for each trial. The dots were presented for 400 ms each, with an interstimulus interval of 300 ms. The spatial version of the missing-item task being employed for the first time, we chose to reduce the TBR list length by one item compared to the verbal version of the task because we expected performance to be too low with 10 spatial locations. Although it turned out that performance in the spatial task was higher than in the verbal task (see results below), the difference in list length between the two tasks did not seem to alter the sensitivity to auditory deviation.

Design and Procedure. As in Experiments 1A and 1B, the design comprised two repeated-measures factors: Task (verbal or spatial) and Deviation-presence (whether or not the irrelevant sequence contained a deviation). The procedure was identical to that of Experiment 1 except as noted below. The TBR verbal items were overlearned stimuli, which was not the case for spatial items. To ensure these unfamiliar spatial locations could be learned properly, each trial of the spatial condition began with the simultaneous presentation of the nine locations for 3 s. Four hundred milliseconds following the offset of the last visual item, participants had to click on the digit (in the verbal task) or the dot (in the spatial task) they thought was missing from the just-presented list using the mouse. They pressed the spacebar to begin the next trial.

Results

Performance in identifying the missing item was submitted to a 2 (Task) × 2 (Deviation-presence) repeated-measures ANOVA in both Experiments 2A and 2B.

Experiment 2A – Verbal deviation. The left panel of Figure 4 shows the mean percentage of responses in which the missing item was identified correctly for each of the four conditions of Experiment 2A. Although performance appeared higher in the spatial task, the correct identification of the missing item seemed lower for deviant trials regardless of the type of task. This was confirmed by the ANOVA as the analysis revealed significant main effects of Task, $F(1, 15) = 73.42$, $p < .001$, $\eta^2 = .830$, and of Deviation-presence, $F(1, 15) = 38.09$, $p < .001$, $\eta^2 = .717$. The two-way interaction was not significant, $F(1, 15) < 1$, $\eta^2 = .005$. Such results point toward a similar verbal deviation effect in both verbal and spatial tasks. A Bayes factor analysis on the same data shows that the Bayes factor for the interaction term is 4.95, under the assumption that the r scale parameter is set to 1. A Bayes factor of this size illustrates positive, but not strong, support for the null-hypothesis.

Figure 4 about here

Experiment 2B – Spatial deviation. The right panel of Figure 4 presents the mean percentage of missing items correctly reported for each of the four conditions of Experiment 2B. The pattern of results was similar to that observed in Experiment 2A with a verbal deviation. The ANOVA revealed significant main effects of Task, $F(1, 21) = 99.00$, $p < .001$, $\eta^2 = .825$, and of Deviation-presence, $F(1, 21) = 16.14$, $p = .001$, $\eta^2 = .435$. Again, the two-way interaction was not significant, $F(1, 21) = 1.53$, $p = .229$, $\eta^2 = .068$. These results suggested a similar detrimental impact of the spatial deviant on performance in both versions of the task. A Bayes factor analysis on the same data shows that the Bayes factor for the interaction term is 3.02, under the assumption that the r scale parameter is set to 1. A Bayes factor of this size indicates positive, but not strong, support for the null-hypothesis.

Cross-experiment analysis. As in Experiment 1, to determine whether the magnitude of the deviation effect differed according to the nature of the deviation, the two versions of Experiment 2 were contrasted in a 2 × 2 × 2 mixed ANOVA with Deviation-type as the between-subjects factor and Task and Deviation-presence as within-subject factors. The analysis revealed that none of the interactions was significant (*p*s > .307), indicating that the pattern of results was similar across Experiments 2A and 2B.

Discussion

The results of Experiments 2A and 2B replicated those of Experiments 1A and 1B by showing, as is the case with order reconstruction, no difference in the disruptive power of verbal and spatial deviations on verbal and spatial STM in the context of a missing-item task. This conclusion was also supported by the outcome of individual Bayes factor analyses. This generalization of domain-aspecific deviation effects from a context in which serial rehearsal is central to the focal activity to a situation in which it constitutes at best a negligible aspect in the task provides further evidence in favor of the non-contingent nature of attentional capture by auditory deviants. The changing-state effect, a phenomenon established as a contingent (or specific) form of auditory distraction, is typically observed in serial recall—a task tapping into serial processing—but not in the missing-item task (Beaman, 1997; Hughes et al., 2007). That the cross-domain deviant effects found with order reconstruction (Experiment 1) also arose in the context of the missing-item paradigm, contrary to the changing-state effect, further supports the duplex-mechanism account of auditory distraction (e.g., Hughes, 2014; Hughes et al., 2007) which stipulates that attentional capture by deviant sounds can take place regardless of the task processes involved.

The impairment of performance in the verbal missing-item task replicated Hughes et al.'s (2007) result showing that this task is sensitive to auditory deviations. The present experiment extended this finding to the spatial domain by showing that the spatial version of the missing-item task can also be disrupted by the presence of a deviant sound. Interestingly, the impact of a deviant, either of verbal or spatial nature, on missing-item recall was similar for both versions of the task despite performance being closer to ceiling in the spatial than in the verbal task. This difference in performance level is probably attributable, at least in part, to the fact that spatial lists contained one item less than verbal lists. Nevertheless, the similarity in the size of the deviation effect between the two tasks extended from order reconstruction to the missing item task. The finding from Experiments 2A and 2B that the disruptive power of deviant sounds is unaltered by the type of TBR material, is predicted by the duplex-mechanism account of auditory distraction.

General Discussion

The aim of the present study was to test whether attentional capture by an auditory deviant is task-contingent form of auditory distraction or not. This was achieved using spatial and verbal order-reconstruction (Experiment 1) and missing-item (Experiment 2) tasks that were completed in the presence of auditory irrelevant sequences that involved either a verbal or spatial deviation. The two experiments revealed the same pattern of results: Performance was equally impaired for both verbal and spatial versions of the STM task by the occurrence of a deviant sound, regardless of whether that sound deviated in the verbal or in the spatial domain. Such results indicate that attentional capture by deviant sound is not contingent on the nature of the auditory deviation, on the relationship between the TBR and TBI material, or on the processes engaged in the focal task. These properties make attentional capture by deviant sounds a general—i.e. non-contingent—form of auditory distraction.

Implications for the Understanding of Auditory Attentional Capture

The present results are consistent with the predictions of the dual-mechanism account of auditory distraction (Hughes, 2014; Hughes et al., 2005, 2007, 2013; Vachon et al., 2012). According to this account, auditory distraction can originate from either the competition between the automatic processing of the auditory environment and a similar process deliberately engaged in a focal activity or the involuntary disengagement of attention away from the prevailing task caused by a deviant sound. On the dual-mechanism account, interference-by-process is assumed to reflect a task-contingent form of distraction while attentional capture is predicted as being non-contingent. This latter prediction supposes that auditory attentional capture should take place regardless of the type of stimulations involved or the nature of the focal task. By equating the procedure for the verbal and the spatial conditions, the present study demonstrated attentional capture whether the deviant sound and the TBR items were from the same domain (e.g., verbal-verbal) or from different domains (e.g., verbal-spatial). Moreover, this finding held whether the focal activity required encoding serial order of items (Experiment 1) or an item regardless of its serial position (Experiment 2). This constitutes, to our knowledge, the first direct empirical support of the prediction made by the dual-mechanism approach of auditory distraction according to which the deviation effect reflects a non-contingent orienting mechanism. Indeed, the phenomenon is neither contingent on stimulus domain nor the relationship between TBR and TBI material nor task requirements.

Also consistent with the duplex-mechanism account, the impairment by deviant sounds in the identification of the missing item found in Experiment 2 provide further, though indirect, evidence for the functional dissociation of attentional capture and interference-by-process. The changing-state effect is the empirical manifestation par excellence of the interference-by-process mechanism. This phenomenon, assumed to be modulated by the interference between the obligatory processing of order in the irrelevant sound and the deliberate seriation processing involved in the focal task (e.g., Jones & Macken, 1993; Jones & Tremblay, 2000; Marsh et al., 2009), typically disappears when the focal task does not encourage serial rehearsal (e.g., Beaman & Jones, 1997; Hughes et al., 2007; Marsh, Hughes, & Jones, 2008; Salamé & Baddeley, 1990). Consistently, the missing-item task, which does not necessitate the retention of serial order, has been shown to be immune to changing-state sound (Beaman & Jones, 1997; Hughes et al., 2007; Jones & Macken, 1993). The demonstration here that this very task is yet susceptible to deviant sounds provide further evidence that the deviation effect is not dependent on a seriation component in the focal task (see also Hughes et al., 2007), contrary to the changing-state effect. Such a finding suggests that the mechanisms responsible for the deviation effect are distinct from those underlying the changing-state effect, confirming that the detrimental impact of deviant sounds cannot be ascribed to interference-by-process.

The present findings provide strong evidence against any account proposing that attentional capture by deviant sounds is mediated by mechanisms that are contingent upon the attentional set and the type of relevant and irrelevant stimulations. For instance, in his pre-attentive activation model, Schröger (1997) postulated the existence of a comparison mechanism that allows for the detection of acoustical discrepancies between the content of the neuronal model and the actual acoustic input. Deviance detection takes place when a variable threshold is exceeded by the output signal of the comparison process. The way this mismatch threshold is set is assumed to be dependent on the attentional set and the relation between task-relevant and task irrelevant aspects of the stimulation. According to this account, then, one would expect to find larger verbal deviation effects when performing a verbal task and larger spatial deviation effects when executing a spatial task. Such a pattern would be especially likely to arise with the missing-item task given that the verbal or spatial identity of the TBR items (and not their order as is the case with serial recall) is key to performing the task. In contrast with this prediction, we obtained similar verbal and spatial deviation effects across the two versions of the memory task, regardless of whether participants had to process serial order (serial recall) or item identity (missing item). These results suggest that the threshold for mismatch signals does not vary as a function of task requirements or the difference between relevant and irrelevant stimuli, at least when the TBR material is visual and the TBI material is auditory. The fact that the threshold appears to be insensitive to task requirements and the relationship between relevant and irrelevant items does not mean that it is not variable at all. In fact, there is evidence that the deviation effect is modulated by task-engagement manipulations (e.g., Hughes et al., 2013; Sörqvist, Stenfelt, & Rönnberg, 2012; see also Marsh et al., 2015) and participants' expectations (e.g., Hughes et al., 2013; Nöstl et al., 2012, 2014), suggesting that the threshold is nevertheless open to top-down cognitive control (cf. Schröger, 1997).

In the same way, the present findings are inconsistent with a domain-specific attentional resources hypothesis which posits that attention operates "in a domain-specific way, so that it is distracted only by irrelevant stimuli from the same domain as the relevant stimuli" (Lange, 2005, p. 517). Indeed, we observed the disruption of verbal STM by a spatial deviation and the impairment of spatial memory by a verbal deviation. If attention was tuned only to the type of stimuli that was relevant to the ongoing task, as would be predicted by the domain-specific attentional resources account, no disruption should have been found in these conditions. At odds with our results, Lange (2005) failed to find an effect of a non-spatial auditory deviation (a change of tone) on spatial serial recall, indicative of a domain-specific form of auditory distraction. In fact, the only ways in which the spatial version of the task was disrupted in her study was by a sudden change of spatial location of a *visual* distractor or the sudden onset of a tone, suggesting that cross-domain distraction was nonetheless possible.

Although Lange's (2005) findings were rather consistent with a domain-specific view of attentional capture, a closer scrutiny of methodological details can help reconcile these findings with the non-contingent view advocated by the duplex-mechanism account of auditory distraction. For example, the difference in sensitivity to the auditory deviant found between the verbal and spatial task may be attributable to some disparities between the verbal and the spatial versions of the serial recall task. Whereas the visual-verbal sequences were composed of eight digits, the spatial sequences were shorter, comprising four to five items. Given that the irrelevant tones were synchronized with the TBR items, this discrepancy in the number of visual—hence auditory—items used in both tasks could have potentially affected the impact of a deviant. Indeed, a deviation effect should be more likely to emerge with longer auditory sequences given that a superior number of sounds would further promote the build-up of a sufficiently well-specified neuronal model (see, e.g., Bendixen et al., 2007; Sams et al., 1984; Vachon et al., 2012). Moreover, with such a small number of dots, it is possible that participants may have formed dot patterns that could have altered the way in which the stimuli were recalled (e.g., Parmentier, Elford, & Maybery, 2005), hence reducing the sensitivity of the spatial task to distraction. The fact that the verbal and spatial tasks yielded different contexts in which the auditory deviation took place may be responsible, at least in part, for the domain-specific deviation effects reported.

In the same vein, even though the spatial task proved to be distractible in Lange's (2005) study, such distraction effects might have ensued from mechanisms different from those responsible for the deviation effect. The disruption caused by a visual distractor location change was likely due to similarity-based interference (i.e., confusion between relevant and irrelevant items) rather than attentional distraction per se (see, e.g., Guérard & Tremblay, 2011). With regards to the impact of the onset of a sound, there is ample psychophysiological evidence that the orienting response triggered by an auditory onset is functionally distinct from the attentional response to a deviant sound (see, e.g., Näätänen, 1990; Näätänen & Picton, 1987; O'Gorman, 1979; Sokolov, Spinks, Näätänen, & Lyytinen, 2002). Overall, it appears that factors other than attentional capture may account for some of Lange's findings. These plausible alternative explanations, combined with the present findings, tend to make the domain-specific account of auditory attentional capture equivocal.

Yet, one can argue that the cross-domain deviation effects observed in the present study actually reflect domain-specific distraction by supposing that the visual items and deviant sounds in those conditions, assumed to afford distinct processing codes, shared nonetheless some code-dependent characteristics. According to this hypothesis, it is possible that verbal TBR material was, to some extent, spatially (re)coded and that the visuospatial stimuli were, at least partially, verbally (re)coded. Although appealing, this assumption is implausible. First of all, Guérard and Tremblay (2008) showed that even though the verbal and spatial versions of the serial recall task were fully equated, as in the current study, articulatory suppression—a concurrent task of verbal nature—interfered more with the verbal than the spatial task while spatial tapping—a concurrent spatial task—was found to be more disruptive of spatial than of verbal performance. Such domain-specific interference suggests that, in the present experimental context, the potential spatial recoding of verbal TBR stimuli as well as the possible verbal recoding of visuospatial TBR material was, at best, very limited.

At the same time, the supposition that participants could have deliberately used verbal codes to remember spatial positions (e.g., 'top-left', 'bottom-right') is unlikely. First, the positions of the dots on the screen were such that the locations were difficult to verbalize (see

Figure 2). Similarly, these positions were not always visible, unlike with the Corsi block task (see, e.g., Kessels, van Zandvoort, Postma, Kappelle, de Haan, 2000), making it more difficult to apply arbitrary verbal labels for each position (cf. Jones et al., 1995). In such a context, the use of a verbal recoding strategy would not necessarily have been of help in preserving serial order in Experiment 1. Furthermore, using the same dot task, Jones and his colleagues (1995) found that spatial serial recall was as susceptible as its verbal counterpart to the changing-state effect. They concluded that their results “cannot be explained by supposing that the to-be-remembered items were verbally recoded, because they showed interference from both changing state spatial material and from changing state verbal material, but not from repeated (steady state) verbal material” (p. 1016).

The same conclusion applies to the spatial-encoding hypothesis of the relevant verbal material. Given that verbal stimuli were always presented at the same location on the screen, the spatial information those stimuli conveyed was uninformative, rending any spatial (re)coding futile to performing the verbal task. Yet, the spatial-numerical association of response codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993) shows how numbers and space can be intimately linked. This automatic and implicit association of numbers with spatial positions is illustrated through the demonstration, for instance, that small numbers (e.g., 0 or 1) tend to be associated with faster left hand responses, and larger numbers (e.g., 8 or 9) with faster right hand responses (e.g., Dehaene et al., 1993), or that participants look toward the left at greater speeds after small numbers are detected, and faster to the right after large numbers are detected (e.g., Fisher, Warlop, Hill, & Fias, 2004). Based on the SNARC effect, one could argue that the use of digits as TBR items in the present experiments may have promoted the implicit spatial encoding of these verbal stimuli, making, in turn, an auditory deviation of spatial nature more potent. However, there is evidence that the SNARC effect becomes stronger when magnitude processing is activated more intensively (see Wood, Willmes, Nuerk, & Fischer, 2008). Accordingly, since the tasks employed in the present study do not foster magnitude processing, especially serial recall which requires strict focus on serial order, any automatic activation of pre-existing associations between numbers and spatial information should have been negligible. Besides, the effects typically found with the serial recall of digits—including the deviation effect—can also be observed with other types of verbal stimuli such as letters and words, indicating that the use of numbers in the context of serial recall is no special case. In summary, the hypothesis according to which the verbal and spatial deviation effects reported here could have been elicited in a domain-specific fashion does not find strong support from the literatures on STM and the SNARC effect.

Our conclusion that the auditory deviation effect reflects a general form of auditory distraction that is independent of what needs to be done and processed, appears incompatible with the proposition that the distractive power of a deviant sound relies only on its informational value. Indeed, some studies reported deviance distraction exclusively when sounds predicted the occurrence of a target stimulus (e.g., Li et al., 2013; Ljungberg et al., 2012; Parmentier et al., 2010). More specifically, in a context where the probabilistic and temporal contingencies between TBI sounds and visual targets were manipulated, the occurrence of a deviant impaired performance when the sounds predicted the presentation and timing of the upcoming target (informative condition), but not when the sounds afforded no such information (uninformative condition). Although such findings appear to cast doubts about the non-contingent nature of auditory attentional capture highlighted in the present study, Dalton and Hughes (2014) claimed that this particular pattern of results is in fact an artefact of the characteristics of the cross-modal oddball paradigm employed in these studies. This paradigm requires participants to perform, on each trial, a speeded categorization task on a simple visual stimulus while ignoring a task-irrelevant sound presented immediately before the target. Attentional capture is indexed by slower response times on deviant trials relative to standard (i.e. no deviant) trials. According to Dalton and Hughes, “the use of speeded performance as the key dependent measure endows the to-be-ignored stimuli with a utility so long as they reliably predict the imminent occurrence of targets. Thus, the behavioural deviation effect in this paradigm may be reliant entirely on the fact that the supposedly task-irrelevant stimuli happen to (usually) facilitate performance in the context of this particular dependent measure” (p. 314). According to this claim, contingent capture effects are expected to emerge in a context where sounds are not completely irrelevant to the focal task such as in the cross-modal oddball paradigm.

In the same vein, Parmentier (2016) recently showed that the apparent absence of distraction for uninformative sounds was rather the consequence of some form of sequence effect. The typical manipulations to render irrelevant sounds uninformative consisted in presenting the sound followed, with equal probabilities, by either a visual target (Go trials) or a fixation cross (No-Go trials) after a variable delay. When comparing performance at these two types of trial, Parmentier observed that response times on Trial *n* were slower (a distraction effect) when a target requiring a response was presented on Trial *n*-1, but were faster (a facilitation effect) following trials involving no target and, thus, requiring no response. When averaged across the experiment, these distraction and facilitation effects were canceling out each other, mimicking the absence of impact of the deviant sound. New analyses of the data of previous studies supporting the informational-value hypothesis (Li et al., 2013; Ljungberg et al., 2012; Parmentier et al., 2010) also revealed distraction following Go trials and facilitation following No-Go trials of the uninformative condition. This presence of deviance distraction for uninformative sounds in the cross-modal oddball paradigm not only undermines the informational-value hypothesis but also provides strong evidence against a task-contingent orienting mechanism underlying attentional capture by auditory deviation. In fact, the finding that both informative and uninformative deviants can capture attention is consistent with our conclusion that the deviation effect reflects a general form of auditory distraction.

At odds with the view that contingent capture occurs only when the sound has informational value, there is evidence that when the occurrence of the target stimulus cannot be predicted by standard and deviant sounds that were genuinely task-irrelevant, attentional capture by auditory deviation was observed (e.g., Dalton & Lavie, 2004). In the present study, deviant sounds were not only unpredictable but also task-irrelevant auditory items (spoken letters presented in the same spatial location) did not convey any information about the upcoming task-relevant visual stimuli (digits displayed in the same location or non-verbal items displayed in different locations) that would have made the sounds ‘useful’ to the focal task. It is thus clear from the present study and previous research using a similar paradigm (e.g., Hughes et al., 2005, 2007; Marsh et al., in press; Sörqvist, 2010; Vachon et al., 2012) that the auditory deviation effect does not rely on whether standard and deviant sounds carry relevant goal-directed information and, therefore, that this phenomenon reflects the non-contingent nature of auditory attentional capture.

Implications for the Understanding of STM

A central question in cognitive psychology is whether STM mechanisms are fractionated or not. Whereas modular conceptualizations of STM, such as the working memory model (Baddeley, 1986, 2000; Baddeley & Hitch, 1974), postulate that verbal and spatial information is processed into separate subsystems, unitary accounts posit instead that the processing of verbal and spatial information is functionally equivalent (e.g., Brown, Neath, & Chater, 2007; Crowder, 1993; Hurlstone & Hitch, 2015; Jones, Hughes, & Macken, 2006). The modular view of STM is bolstered by the observation of dissociations between the processing of spatial and verbal information. For instance, in dual-task studies, verbal STM tasks tend to be susceptible to interference from verbal, but not spatial secondary tasks whereas their spatial counterparts tend to be sensitive to interference from spatial, but not verbal secondary tasks (e.g., Farmer, Berman, & Fletcher, 1986; Guérard & Tremblay, 2008; Meiser & Klauer, 1999). The unitary view of STM is supported by the demonstration of similarities between the verbal and spatial domains, such as the presence of serial position curves with primacy and recency effects in both verbal and spatial serial recall (e.g., Guérard & Tremblay, 2008; Jones et al., 1995).

Although deviation effects are not dependent upon a task tapping on STM (e.g., Nöslt et al., 2012, 2014), the actual demonstration that the deviation effect is domain-independent provides support for the unitary view of STM. Indeed, deviations in the verbal domain impeded not only with verbal recall but also with spatial recall while the interference from deviations in the spatial domain was not restricted to spatial STM tasks. This was true whether the focus was on serial order (Experiment 1) or verbal or spatial identity (Experiment 2). Despite the fact that participants were not engaged in the active processing of the auditory stream while performing the STM task as in dual-task settings, a modular approach to STM predicts selective deviant interference whereby the deviant effect would be restricted to situations in which the deviation and TBR items occur in the same domain. Indeed, it is difficult for the working memory model to explain, for instance, how auditory verbal information—afforded by an unexpected change in the verbal content of a sound—can interfere with the deliberate processing of visual spatial information while these two types of information are assumed to be subtended by distinct subsystems, i.e. the phonological loop and the visuospatial sketchpad, respectively.

One may argue that present findings are also consistent with a modular view of STM that postulates the existence of two subsystems processing verbal and spatial information separately but in a functionally similar fashion (e.g., Hurlstone, Hitch, & Baddeley, 2014; Logie, 1995; see also Guérard & Tremblay, 2008). Although plausible, this notion that two distinct modules process different forms of information in the exact same way is rather unparsimonious. Nevertheless, the across-domain distraction demonstrated in the present study may inform the debate concerning the extent to which verbal and spatial information is processed in a functionally similar fashion in STM.

Conclusion

The weight of evidence suggests that auditory attentional capture by unexpected task-irrelevant verbal or spatial sounds appears to be stimulus-driven rather than contingent on attentional set. This would seem intuitive from a functional point of view since the alerting capacity of the auditory attentional capture mechanism should ensure the organism attends to the capturing event regardless of the nature of the currently attended goal, the informational value of the task-irrelevant sound and any coupling between relevant and irrelevant information. Furthermore, the focussing on internal events that may, or may not, have activation via external origin (such as thinking and reasoning as well as rehearsal) must be equally amenable to attentional disengagement to alert the organism to changes within its environment.

References

Baddeley, A. (1986). *Working memory*. Oxford, England: Clarendon Press.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, *4*, 417-423.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (vol. 8, pp. 47-89). New York, NY: Academic Press.

Beaman, C. P., & Jones, D. M. (1997). The role of serial order in the irrelevant speech effect: Tests of the changing state hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 459-471.

Belopolsky, A. V., Schreij, D., & Theeuwes, J. (2010).What is top-down about contingent capture? *Attention, Perception & Psychophysics*, *72*, 326-341.

Bendixen, A., Roeber, U., & Schröger, E. (2007). Regularity extraction and application in dynamic auditory stimulus sequences. *Journal of Cognitive Neuroscience*, *19*, 1664-1677.

Brown, G. D. A., Neath, I., & Chater, N. (2007). A ratio model of scale-invariant memory and identification. *Psychological Review*, *114*, 539-576.

Buschke, H. (1963). Relative retention in immediate memory determined by the missing scan method. *Nature*, *200*, 1129-1130.

Colle, H. A., & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior*, *15*, 17-31.

Cowan, N. (1995). *Attention and memory: An integrated framework*. Oxford, England: Oxford University Press.

Crowder, R. G. (1993). Systems and principles in memory theory: Another critique of pure memory. In A. F. Collins, S. E. Gathercole, M. A. Conway, & P. E. Morris (Eds.), *Theories of memory* (pp. 139-161). Hillsdale, NJ: Erlbaum.

Dalton, P., & Hughes, R. W. (2014). Auditory attentional capture: Implicit and explicit approaches. *Psychological Research*, *78*, 313-320.

Dalton, P., & Lavie, N. (2004). Auditory attentional capture: Effects of singleton distractor sounds. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 180-193.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*, 371-396.

Eimer, M., & Kiss, M. (2008) Involuntary attentional capture is determined by task set: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience*, *20*, 1423-1433.

Escera, C., Alho, K., Winkler, I., & Näätänen, R. (1998). Neural mechanisms of involuntary attention to acoustic novelty and change. *Journal of Cognitive Neuroscience*, *10*, 590-604.

Farmer, E. W., Berman, J. V. F., & Fletcher, Y. L. (1986). Evidence for a visuo-spatial scratch-pad in working memory. *Quarterly Journal of Experimental Psychology*, *38A*, 675-688.

Fischer, M. H., Warlop, N., Hill, R. L., & Fias, W. (2004). Oculomotor bias induced by number perception. *Experimental Psychology*, *51*, 1-7.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992) Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030-1044.

Guérard, K., & Tremblay, S. (2008). Revisiting evidence for modularity and functional equivalence across verbal and spatial domains in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 556-569.

Guérard, K., & Tremblay, S. (2011). When distractors and TBR items compete for the control of action: A new perspective of serial memory for spatial information. *Journal of Experimental Psychology: Human Perception and Performance, 37*, 834-843.

Hughes, R. W. (2014). Auditory distraction: A duplex-mechanism account. *PsyCH Journal, 3*, 30-41.

Hughes, R.W., Hurlstone, M. J., Marsh, J. E., Vachon, F., & Jones, D. M. (2013). Cognitive control of auditory distraction: Impact of task difficulty, foreknowledge, and working memory capacity supports duplex-mechanism account. *Journal of Experimental Psychology: Human Perception and Performance, 39*, 539-553.

Hughes, R. W., & Jones, D. M. (2003). Indispensable benefits and unavoidable costs of unattended sound for cognitive functioning. *Noise & Health, 6*, 63-76.

Hughes, R. W., Tremblay, S., & Jones, D. M. (2005). Disruption by speech of serial short-term memory: The role of changing-state vowels. *Psychonomic Bulletin & Review, 12*, 886-890.

Hughes, R. W., Vachon, F., & Jones, D. M. (2005). Auditory attentional capture during serial recall: Violations at encoding of an algorithm-based neural model? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 736-749.

Hughes, R. W., Vachon, F., & Jones, D. M. (2007). Disruption of short-term memory by changing and deviant sounds: Support for a duplex-mechanism account of auditory distraction. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 1050-1061.

Hurlstone, M. J., & Hitch, G. J. (2015). How is the serial order of a spatial sequence represented? Insights from transposition latencies. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*, 295-324.

Hurlstone, M. J., Hitch, G. J., & Baddeley, A. D. (2014). Memory for serial order across domains: An overview of the literature and directions for future research. *Psychological Bulletin*, *140*, 339-373.

Jones, D. M., Farrand, P., Stuart, G., & Morris, N. (1995). Functional equivalence of verbal and spatial information in serial short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 1008-1018.

Jones, D. M., Hughes, R., W., & Macken, W. J. (2006). Perceptual organization masquerading as phonological storage: Further support for a perceptual–gestural view of short-term memory. *Journal of Memory and Language*, *54*, 265-281.

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 369-381.

Jones, D., Madden, C., & Miles, C. (1992). Privileged access by irrelevant speech to short-term memory: The role of changing state. *Quarterly Journal of Experimental Psychology*, *44A*, 645-669.

Jones, D. M., Marsh, J. E., & Hughes, R.W. (2012). Retrieval from memory: Vulnerable or inviolable? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*, 905-922.

Jones, D. M., & Tremblay, S. (2000). Interference in memory by process or content? A reply to Neath (2000). *Psychonomic Bulletin & Review*, *7*, 550-558.

Jonides, J. (1981) Voluntary versus automatic control over the mind's eye's movement. In J. B. Long and A. D. Baddeley (Eds.), *Attention and Performance IX* (pp. 187–203). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kessels, R. P. C., van Zandvoort, M. J. E., Postma, A., Kappelle, L. J., & de Haan, E. H. F. (2000). The Corsi block-tapping task: Standardization and normative data. *Applied Neuropsychology, 7*, 252-258.

Lange, E. B. (2005). Disruption of attention by irrelevant stimuli in serial recall. *Journal of Memory and Language, 53*, 513-531.

Li, Parmentier, & Zhang (2013). Behavioral distraction by auditory deviance is mediated by the sound's informational value: Evidence from an auditory discrimination task. *Experimental Psychology, 60*, 260-268.

Ljungberg, J. K., Parmentier, F. B. R., Leiva, A., & Vega, N. (2012). The informational constraints of behavioral distraction by unexpected sounds: The role of event information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*, 1461-1468.

Logie, R. H. (1995). *Visuo-spatial working memory*. Hillsdale, NJ: Erlbaum.

Marsh, J. E., Hughes, R. W., & Jones, D. M. (2008). Auditory distraction in semantic memory: A process-based approach. *Journal of Memory and Language, 58*, 682-700.

Marsh, J. E., Hughes, R. W., & Jones, D. M. (2009). Interference by process, not content, determines semantic auditory distraction. *Cognition, 110*, 23-38.

Marsh, J. E., & Jones, D. M. (2010). Cross-modal distraction by background speech: What role for meaning? *Noise & Health, 12*, 210-216.

Marsh, J. E., Röer, J. P., Bell, R., & Buchner, A. (2014). Predictability and distraction: Does the neural model represent postcategorical features? *PsyCh Journal, 3*, 58-71.

Marsh, J. E., Sörqvist, P., & Hughes, R. W. (2015). Cognitive control of irrelevant sound: Increased task engagement attenuates semantic auditory distraction. *Journal of Experimental Psychology: Human Perception and Performance, 41*, 1462-1474.

Marsh, J. E., Vachon, F., & Jones, D. M. (2008). When does between-sequence phonological similarity promote irrelevant sound disruption? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 243-248.

Marsh, J. E., Vachon, F., & Sörqvist, P. (in press). Increased distractibility in schizotypy: Independent of individual differences in working memory capacity? *Quarterly Journal of Experimental Psychology*.

Meiser, T., & Klauer, K. C. (1999). Working memory and changing state hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 1272-1299.

Murdock, B. B., Jr. (1993). TODAM2: A model for the storage and retrieval of item, associative, and serial-order information. *Psychological Review, 100*, 183-203.

Näätänen, R. (1990). The role of attention in auditory information processing as revealed by event-related and other brain measures of cognitive function. *Behavioral and Brain Sciences, 13*, 201-233.

Näätänen, R., & Picton, T. W. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*, 375-425.

Nöstl, A., Marsh, J. E., & Sörqvist, P. (2012). Expectations modulate the magnitude of attentional capture by auditory events. *PLoS ONE 7*(11), e48569.

Nöstl, A., Marsh, J. E., & Sörqvist, P. (2014). What we expect is not always what we get: Evidence for both the direction-of-change and specific-stimulus hypotheses of auditory attentional capture. *PLoS ONE 9*(11), e111997.

O'Gorman, J. G. (1979). The orienting reflex: Novelty or significance detector? *Psychophysiology, 16*, 253-262.

Paavilainen, P., Karlsson, M.-L., Reinikainen, K., & Näätänen, R. (1989). Mismatch negativity to change in spatial location of an auditory stimulus. *Electroencephalography and Clinical Neurophysiology, 73*, 129-141.

Parmentier, F. B. R. (2016). Deviant sounds yield distraction irrespective of the sounds' informational value. *Journal of Experimental Psychology: Human Perception and Performance, 42*, 837-846.

Parmentier, F. B. R., Elford, G., Escera, C., Andrés, P., & San Miguel, I. (2008). The cognitive locus of distraction by acoustic novelty in the cross-modal oddball task. *Cognition, 106*, 408-432.

Parmentier, F. B. R., Elford, G., & Maybery, M. T. (2005). Transitional information in spatial serial memory: Path characteristics affect recall performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 412-427.

Parmentier, F. B. R., Elsley, J. V., Andrés, P., & Barceló, F. (2011). Why are auditory novels distracting? Contrasting the roles of novelty, violation of expectation and stimulus change. *Cognition, 119*, 374-380.

Parmentier, F. B. R., Elsley, J. V., & Ljungberg, J. K. (2010). Behavioral distraction by auditory novelty is not only about novelty: The role of the distracter's informational value. *Cognition, 115*, 504-511.

Roeber, U., Widmann, A., & Schröger, E. (2003). Auditory distraction by duration and location deviants: A behavioral and event-related potential study. *Cognitive Brain Research, 17*, 347-357.

Salamé, P., & Baddeley, A. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behavior, 21*, 150-164.

Salamé, P., & Baddeley, A. (1990). The effects of irrelevant speech on immediate short-term memory. *Bulletin of the Psychonomic Society, 28*, 540-542.

Sams, M., Alho, K., & Näätänen, R. (1984). Short-term habituation and dishabituation of the mismatch negativity of the ERP. *Psychophysiology, 21*, 434-441.

Schröger, E. (1997). On the detection of auditory deviants: A pre-attentive activation model. *Psychophysiology, 34*, 245-257.

Schröger, E., Bendixen, A., Trujillo-Barreto, N. J., & Roeber, U. (2007). Processing of abstract rule violations in audition. *PLoS ONE 2*(11), e1131.

Schröger, E., & Wolff, C. (1998). Behavioral and electrophysiological effects of task-irrelevant sound change: A new distraction paradigm. *Cognitive Brain Research, 7*, 71-87.

Sokolov, E. N. (1963). *Perception and the conditioned reflex*. London, England: Pergamon Press.

Sokolov, E. N., Spinks, J. A., Näätänen, R., & Lyytinen, H. (2002). *The orienting response in information processing.* Mahwah, NJ: Erlbaum.

Sörqvist, P. (2010). High working memory capacity attenuates the deviation effect but not the changing-state effect: Further support for the duplex-mechanism account of auditory distraction. *Memory & Cognition, 38*, 651-658.

Sörqvist, P., Marsh, J. E., & Nöstl, A. (2013). High working memory capacity does not always attenuate distraction: Bayesian evidence in support of the null hypothesis. *Psychonomic Bulletin & Review, 20*, 897-904.

Sörqvist, P., Stenfelt, S., & Rönnberg, J. (2012). Working memory capacity and visual-verbal cognitive load modulate auditory-sensory gating in the brainstem: Toward a unified view of attention. *Journal of Cognitive Neuroscience, 24*, 2147-2154.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 799-806.

Theeuwes, J., Olivers, C. N. L., & Belopolsky, A. (2010). Stimulus-driven capture and contingent capture. *WIREs Cognitive Science, 1*, 872-881.

Vachon, F., Hughes, R. W., & Jones, D. M. (2012). Broken expectations: Violation of expectancies, not novelty, captures auditory attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*, 164-177.

Wetzel, N., Schröger, E., & Widmann, A. (2013). The dissociation between the P3a event-related potential and behavioral distraction. *Psychophysiology*, *50*, 920-930.

Wetzel, N., Widmann, A., & Schröger, E. (2012). Distraction and facilitation—two faces of the same coin? *Journal of Experimental Psychology: Human Perception and Performance, 38*, 664-674.

Winkler, I., Denham, S. L., & Nelken, I. (2009). Modeling the auditory scene: Predictive regularity representations and perceptual objects. *Trends in Cognitive Sciences, 13*, 532-540.

Winkler, I., Tervaniemi, M., Schröger, E., Wolff, C., & Näätänen, R. (1998). Preattentive processing of auditory spatial information in humans. *Neuroscience Letters, 242*, 49-52.

Wood, G., Willmes, K., Nuerk, H., & Fischer, M. H. (2008). On the cognitive link between space and number: A meta-analysis of the SNARC effect. *Psychology Science Quarterly, 50*, 489-525.

Yantis, S. & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 121-134.

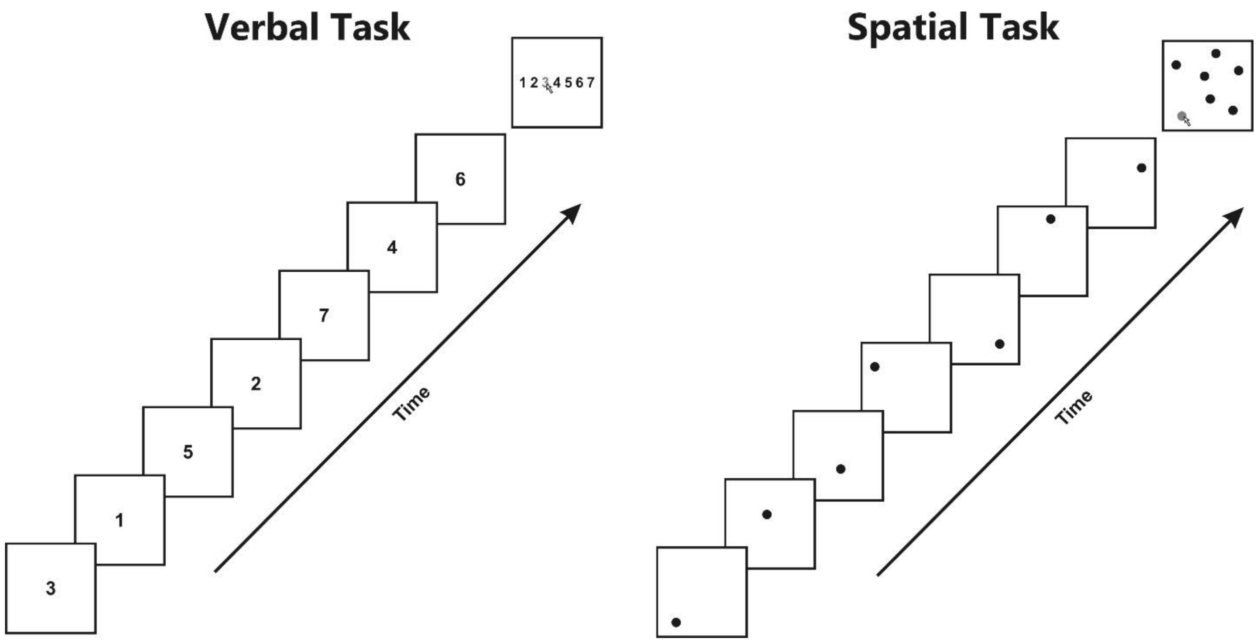


Figure 1. Schematic diagram of the TBR lists used in the verbal and spatial tasks of Experiment 1: Representation of the sequential presentation of the seven items (digits or dots) and of the response procedure.

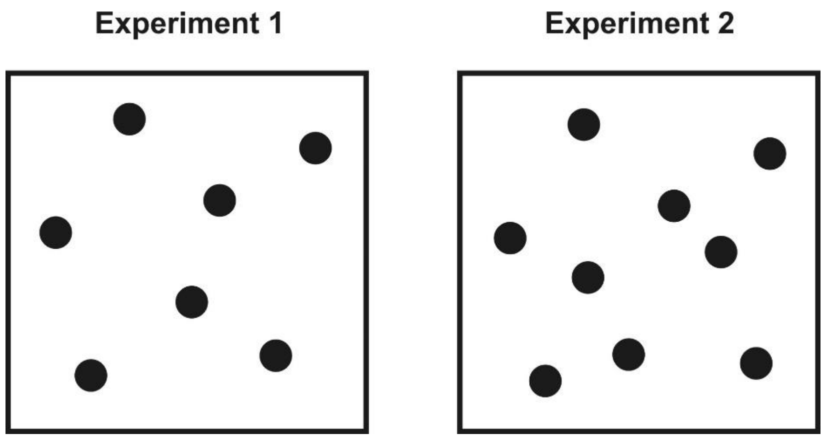


Figure 2. Schematic illustration of the spatial configuration of the seven dots used in the serial-recall task of Experiment 1 and of the nine dots used the missing-item task of Experiment 2. The illustration is not to scale.

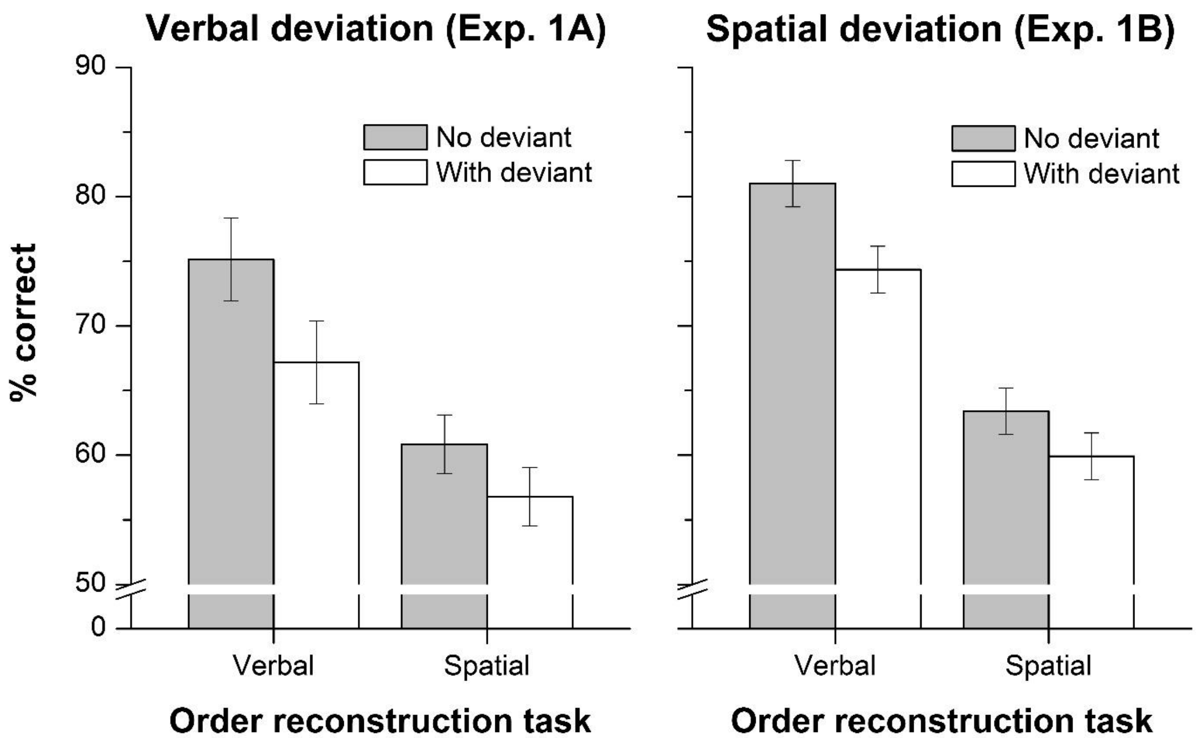


Figure 3. Results from Experiment 1: Mean percentage of items correctly recalled in the presence and the absence of a verbal deviant (left panel) and a spatial deviant (right panel) for both verbal and spatial serial recall conditions. Error bars represent 95% within-subject confidence intervals computed to allow pairwise mean comparison.

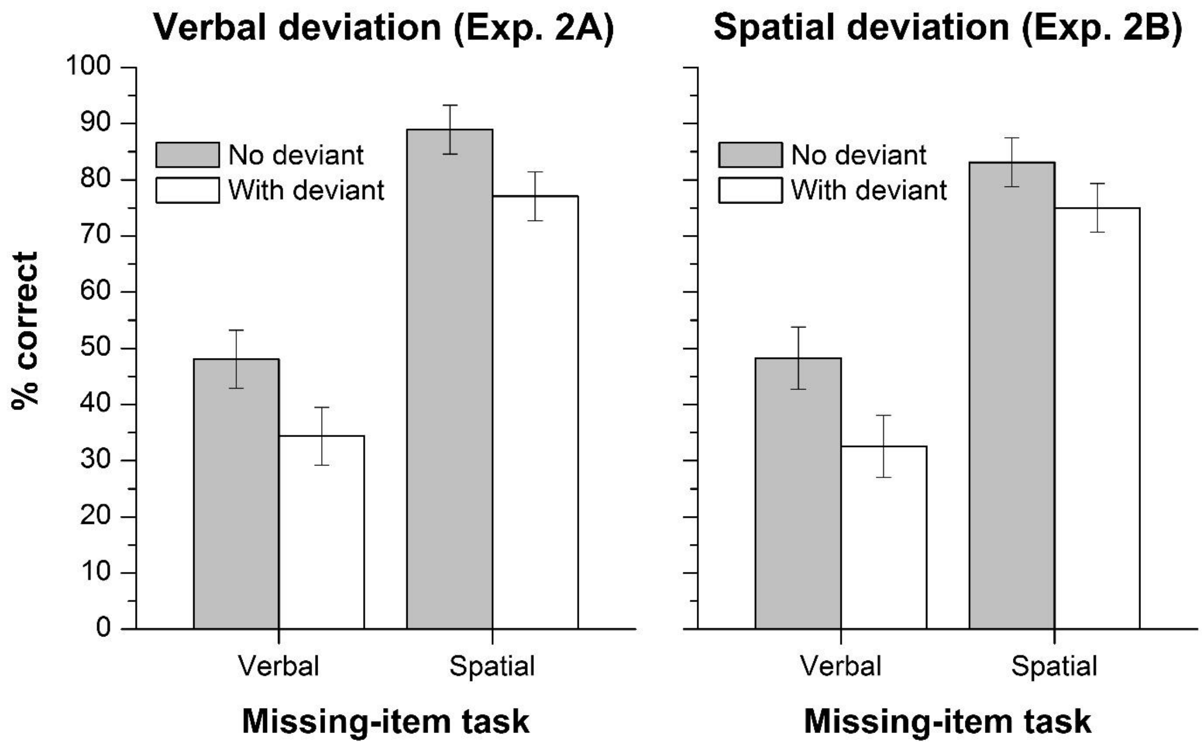


Figure 4. Results from Experiment 2: Mean percentage of missing items identified in the presence and the absence of a verbal deviant (left panel) and a spatial deviant (right panel) for both verbal and spatial tasks. Error bars represent 95% within-subject confidence intervals computed to allow pairwise mean comparison.