Journal of Experimental Psychology:
Human Perception and Performance
2013, Vol. 39, No. 2, 539–553

0096-1523/13/$12.00 DOI: 10.1037/a0029064

Cognitive Control of Auditory Distraction: Impact of Task Difficulty, Foreknowledge, and Working Memory Capacity Supports Duplex-Mechanism Account

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The influence of top-down cognitive control on 2 putatively distinct forms of distraction was investigated. Attentional capture by a task-irrelevant auditory deviation (e.g., a female-spoken token following a sequence of male-spoken tokens)—as indexed by its disruption of a visually presented recall task—was abolished when focal-task engagement was promoted either by increasing the difficulty of encoding the visual to-be-remembered stimuli (by reducing their perceptual discriminability; Experiments 1 and 2) or by providing foreknowledge of an imminent deviation (Experiment 2). In contrast, distraction from continuously changing auditory stimuli ("changing-state effect") was not modulated by task-difficulty or foreknowledge (Experiment 3). We also confirmed that individual differences in working memory capacity—typically associated with maintaining task-engagement in the face of distraction—predict the magnitude of the deviation effect, but not the changing-state effect. This convergence of experimental and psychometric data strongly supports a duplex-mechanism account of auditory distraction: Auditory attentional capture (deviation effect) is open to top-down cognitive control, whereas auditory distraction caused by direct conflict between the sound and focal-task processing (changing-state effect) is relatively immune to such control.

Keywords: cognitive control, auditory distraction, attentional capture, interference-by-process, working memory capacity

Attentional selectivity involves a delicate balance between two countervailing forces: selection of the subset of available sensory information most relevant to current goals (focusability) and the need to remain open to the influence of task-irrelevant input (distractibility) so as to be receptive to potentially important events within the unattended scene (e.g., Allport, 1989; Johnston & Strayer, 2001). Although distractibility is adaptive generally, it can often lead to the disruption of focal cognitive performance (e.g., Driver, 2001; Hughes & Jones, 2003b; Yantis, 2000). In the present article, we ask: to what extent is unwanted distraction tempered by top-down cognitive control? We study the ways in which top-down influences modulate distraction using, as a vehicle for study, the effects of task-irrelevant auditory stimuli on visually presented serial recall (e.g., Beaman, 2004; Colle & Welsh, 1976; Hughes & Jones, 2003b, 2005; Macken, Tremblay, Houghton, Nicholls, & Jones, 2003; Salamé & Baddeley, 1982). In line with a recently developed *duplex-mechanism account* of auditory distraction (Hughes, Vachon, & Jones, 2005, 2007)—contrary to single-mechanism approaches (Chein & Fiez, 2010; Cowan, 1995; Elliott, 2002)—we report the first experiments demonstrating a distinction between a form of auditory distraction that is modulated by top-down attentional control and one that seems to bypass such control.

Duplex- Versus Single-Mechanism Accounts of Auditory Distraction

Recent evidence suggests that human performance is susceptible to auditory distraction in two functionally distinct ways. On the duplex-mechanism account (Hughes et al., 2007; Hughes, Vachon, & Jones, 2005), one form of auditory distraction results from a

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The research reported in this article received financial support from the United Kingdom's Economic and Social Research Council in the form of grants awarded to Robert W. Hughes and Dylan M. Jones (RES-000-22-4257), and to Dylan M. Jones, Robert W. Hughes, and Bill Macken (RES-062-23-0011). François Vachon received support from the Fonds québécois de recherche sur la nature et les technologies in the form of a postdoctoral fellowship.

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conflict between the obligatory processing of the sound and the processing deployed to perform the focal task (e.g., Hughes, Tremblay, & Jones, 2005; Jones & Tremblay, 2000). Such *interference-by-process* has been demonstrated mainly using a serial recall task in which a short list of (usually visually presented) items (e.g., digits or letters) must be reproduced in serial order. To-be-ignored sound that is changing acoustically from one segmentable entity to the next (e.g., "k g m q . . ." or tones changing in frequency) disrupts serial recall appreciably compared with a repeated sound (e.g., "k k k k . . ." or the same tone repeated), which in turn produces relatively little if any disruption compared with quiet (Elliott, 2002; Jones & Macken, 1993; Jones, Madden, & Miles, 1992). On the interference-by-process account, changes between successive sound tokens yield cues relating to their order as a by-product of preattentive streaming processes (cf. Bregman, 1990), such order cues being minimal or nonexistent with a repeated item. These order cues are processed obligatorily and compete for inclusion in, and hence interfere with, the deliberate process of establishing and maintaining a motor sequence-plan (serial rehearsal) subserving the reproduction of the to-be-remembered list (e.g., Hughes & Jones, 2003a, 2005; Macken et al., 2003; for extensions of the interference-by-process account beyond serial recall, see Jones, Marsh, & Hughes, 2012; Marsh, Hughes, & Jones, 2008, 2009; see also General Discussion).

The second mechanism of auditory distraction within the duplex-mechanism account is *attentional capture.* Here, an auditory stimulus that is salient, such as one endowed with personal significance (e.g., one's own name; Conway, Cowan, & Bunting, 2001; Moray, 1959) or, of particular relevance to the present studies, one that deviates from the recent auditory context (Hughes et al., 2007; Hughes, Vachon, & Jones, 2005; Näätänen, 1990; Parmentier, 2008; Schröger, 1996), disrupts performance by drawing attention away from the prevailing task. This effect can again be witnessed using visual-verbal serial recall as a focal task: Recall is impaired if, on a small proportion of trials, an irrelevant speech sequence contains one speech token that is, for example, out of rhythm with (Hughes, Vachon, & Jones, 2005), or conveyed in a different voice from, the preceding sequence of tokens (Hughes et al., 2007; see also Lange, 2005; Sörqvist, 2010; Vachon, Hughes, & Jones, 2012).

The duplex-mechanism account of auditory distraction stands as an alternative to a single-mechanism approach. On the latter approach, the changing-state effect, as well as the deviation effect, is underpinned by attentional capture (Chein & Fiez, 2010; Cowan, 1995; Elliott, 2002). Rather than disrupting performance by yielding order cues that conflict specifically with focal processing, this view supposes that because each item in a changing-state (but not steady-state) sequence mismatches its predecessor(s)—just as is the case with a single deviant—attention is repetitively captured from the task. However, a major stumbling block for the single-mechanism approach is that the changing-state effect, but not the deviation effect, is codetermined by the nature of the processing involved in the focal task: The changing-state effect—as predicted by the interference-by-process account—is only found in serial recall and other tasks that involve or tend to be performed using a sequencing process (Beaman & Jones, 1997; Hughes et al., 2007; Jones & Macken, 1993), whereas the disruptive effect of a deviant, while observable in serial recall, is also found across a whole range of focal tasks devoid of an obvious sequencing component (e.g., speeded classification of individual visual stimuli; Parmentier, 2008; cross-modal Stroop; Elliott & Cowan, 2001; identification of an item missing from a well-known set; Hughes et al., 2007). Thus, in line with a duplex-mechanism account, attentional capture seems to be a general (focal-task process-insensitive) task-disengagement mechanism. However, interference-by-process is, necessarily, tied to the act of engaging in the particular focal task. Despite burgeoning evidence in favor of the duplex view, several recent theoretical treatments continue to assert that the changing-state effect is caused by attentional capture (Bell, Dentale, Buchner, & Mayr, 2010; Chein & Fiez, 2010; Weisz & Schlittmeier, 2006; see also Rinne, Sarkka, Degerman, Schroger, & Alho, 2006; Schlittmeier, Weisz, & Bertrand, 2011). One key purpose of the present research was to provide new evidence for the duplex position, addressed from the novel standpoint of whether the deviation effect and the changing-state effect are differentially amenable to top-down control.

Resistible and Indomitable Forms of Auditory Distraction?

There is general consensus that the balance between focusability and distractibility is to some extent under the influence of top-down cognitive factors (see, e.g., Monsell & Driver, 2000). That is, distractibility is not only a function of the nature of the distracting stimuli (bottom-up factors), but also the individual's internal state (e.g., immediate goals and intentions; see, e.g., Duncan, 1993) as well as their trait (i.e., long-term and stable) capacity for focal task-engagement ("working memory capacity"; Engle & Kane, 2004; see also below). In particular, the present work is predicated on the idea that distraction resulting from focal process-insensitive disengagement of attention from a focal task (e.g., deviation effect) should be reduced by top-down factors that promote general task-engagement, whereas distraction arising from a specific competition between irrelevant and task processing (e.g., changing-state effect) should not:

> Real limitations of goal-schema translation mechanisms should give rise to interference effects that are unavoidable and robust in the sense that such effects should be present even when attention is tightly focused on the instructed task and the associated task goal fully activated. Conversely, interference effects that can be shown to be largely eliminated in conditions that promote appropriate focusing on the relevant task goal, should be attributed to failures of focused attention. (De Jong, Berendsen, & Cools, 1999, p. 382)

According to our duplex-mechanism account, then, increased focal-task engagement should shield performance from attentional capture by a deviant: the more steadfast the task engagement, the less likelihood of attention being drawn away by a deviant event. In contrast, greater focal-task engagement should not attenuate the changing-state effect because it is precisely the act of engaging in the focal task—through serial rehearsal—that underpins this type of distraction. On the single-mechanism approach, greater focal-task engagement should attenuate not only the deviation effect but also the changing-state effect because the latter is also attributed in this approach to attention being drawn away from the focal task.

Our prediction that the deviation effect will be attenuated to a greater extent by increased focal-task engagement than the changing-state effect receives some support from extant psychometric findings relating to working memory capacity. Individual differences in working memory capacity—as measured, for example, by the Operation Span Task (OSPAN) in which words to be recalled are interleaved with simple to-be-solved mathematical equations (Turner & Engle, 1989)—have attracted a great deal of interest because they are excellent predictors of critical "higher-order" capabilities including language comprehension, learning, and fluid reasoning. Furthermore, they also predict "lower-order" attentional capacities such as those measured by the antisaccade task, Eriksen's flanker task and the Stroop task (for a review, see Unsworth & Engle, 2007). This covariation has led to the widespread view that "individual differences in WMC [working memory capacity] are . . . about executive control in maintaining goal-relevant information in a highly active, accessible state under conditions of interference or competition" (Engle & Kane, 2004, p. 149). Critical for our present purposes is the recent finding that individuals high in working memory capacity are also less susceptible to attentional capture by a deviant during serial recall (Sörqvist, 2010; for a related finding, see Conway et al., 2001). In contrast, several studies have repeatedly failed to find any relationship between working memory capacity and the changing-state effect (Beaman, 2004; Ellermeier & Zimmer, 1997; Elliott & Cowan, 2005; Neath, Farley, & Surprenant, 2003; Sörqvist, 2010). These results are clearly consistent with the view that the deviation effect is more amenable to top-down influences than the changing-state effect.

In the present study, we provide the first direct experimental tests of the hypothesis that the deviation effect will be sensitive to top-down influences that facilitate general focal task-engagement, whereas the changing-state effect will be less so, if at all. Such a result would clearly support the duplex-mechanism account (Hughes et al., 2007) over single-mechanism accounts of auditory distraction (e.g., Chein & Fiez, 2010; Cowan, 1995).

Experiment 1

We begin the series by examining whether conditions designed to promote focal-task engagement attenuate attentional capture by a voice deviant embedded in a task-irrelevant sound sequence during visual-verbal serial recall (e.g., Hughes et al., 2007; Hughes, Vachon, & Jones, 2005). Specifically, we sought to influence the degree to which attention would need to be actively engaged on the focal task by increasing task difficulty, specifically the difficulty of identifying the to-be-remembered items. As shown in the right panel of Figure 1, in the high task-difficulty condition, each to-be-remembered item was made more transparent and embedded in static visual noise (cf. Parmentier, Elford, Escera, Andrés, & San Miguel, 2008; see also Yi, Woodman, Widders, Marois, & Chun, 2004; see the Method section for further details). This was compared with a low task-difficulty condition in which each of the digits was presented in the usual fashion: clearly in black against a white background (cf. left panel of Figure 1).

We reasoned that the greater task-difficulty in the degraded condition—an assumption corroborated independently by pilot work (reported below)—would promote active focal task-engagement, and in turn, it would shield performance from attentional capture by an irrelevant auditory deviant. Indirect neuroscientific evidence consistent with this expectation comes from the finding that when an auditory deviant is presented during a visual tracking task, the P3a component of the auditory event-related potential (ERP)—a component thought to reflect attentional capture by the deviant (Escera, Alho, Schröger, & Winkler, 2000)—is attenuated if the number of targets to be tracked is increased (Zhang, Chen, Yuan, Zhang, & He, 2006). Moreover, in an intra-visual setting, Yi et al. (2004) found that neural processing (based on fMRI) associated with task-irrelevant background visual scenes was attenuated if the centrally presented target stimuli (faces) were masked by static visual noise. In Experiment 1, we seek direct behavioral evidence for the attenuation of auditory attentional capture due to increased attentional engagement in a visually presented task.

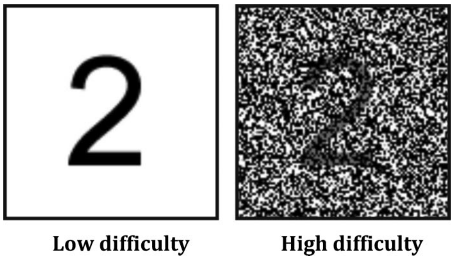

Figure 1. Illustration of how one of the to-be-remembered digits appeared in the low task-difficulty and high task-difficulty conditions. Note: All to-be-remembered stimuli in a given list were either all clearly visible (low task-difficulty condition) or visually degraded (high task-difficulty condition).

Method

Participants. Twenty-seven Cardiff University psychology students took part in the experiment in return for course credits. All reported normal hearing and normal or corrected-to-normal vision.

Apparatus and materials.

To-be-remembered items. The visual to-be-remembered lists comprised eight digits sampled without replacement from the set *1–8*, arranged in a quazi-random order with the constraint that there were no ascending or descending runs of more than two digits. The digits were presented one at a time in the central position of the computer display for 350 ms each, with a 450 ms interstimulus interval. Two versions of the eight digits were created and saved as bitmap files on the computer controlling stimulus presentation. In one set, the digits were clearly visible, whereas in the second set the digits were degraded by adding a visual mask comprising static Gaussian visual noise (400%) over the item, and by setting the transparency of the item to 50% using the Adobe Photoshop software. For both sets, the digit sustained an angle of about 2.6º (participants sat at approximately 50 cm from the screen). Figure 1 provides an illustration of one of the items from the nondegraded (left panel) and the degraded (right panel) sets.

A pilot study was conducted to determine whether degrading the items did indeed make stimulus identification more difficult, and it is reported here briefly: Ten participants (all students at Cardiff University who did not partake in the experiments proper) were required to classify individually presented visual stimuli (presented for 1 s each) as being either a digit (taken from the set *1–8*—the same stimuli that were then used in the serial recall experiment) or a letter (*B, F, H, L, Q, R, Y,* or *X*) as quickly and as accurately as possible by pressing one of two buttons. The stimuli were presented either clearly, or they were presented in the degraded fashion described earlier. The results corroborated the effectiveness of the degradation manipulation: Speeded classification times were significantly slower when the stimuli were degraded ($M = 556.25$ ms, $SE = 12.92$) than when they were not ($M = 476.95$ ms, $SE = 12.95$), $t(9) = 20.84$, $p < .001$. Participants' accuracy was high in, and did not differ between, the two conditions: $M = 92.71\%$ correct, $SE = 1.24$, for nondegraded and $M = 92.81\%$, $SE = 1.16$, for degraded, $t(9) < 1$.

To-be-ignored auditory sequences. For the irrelevant auditory sequences, two sets of 10 spoken letters (*A, B, C, G, J, K, L, M, Q,* and *S*) were recorded: one set in a distinctively female voice and another in a distinctively male voice. Within each set, the letters were recorded in a monotone voice, they were recorded to 16-bit resolution at 22 kHz sampling rate using Sony Sound Forge 8.0 software (Sony Creative Software), and they were made equivalent in loudness (approximately 65dB[A]) and duration (250 ms). Two types of to-be-ignored auditory sequence were created: In "no deviant" sequences, all 10 letters were presented (in a different random order for each trial) in the same voice (e.g., female). The "deviant" sequences were identical to "no deviant" sequences except that the sixth letter was conveyed in the other (e.g., male) voice. Regardless of condition, the onset of the to-be-ignored auditory sequence preceded the onset of the first to-be-remembered digit by 150 ms, with a 350 ms interstimulus interval between each spoken letter. Using these timing parameters, the voice-deviant on "deviant" trials occurred 125 ms before the fifth to-be-remembered item. The auditory sequences were presented via headphones at a sound level of approximately 65dB(A). The experiment was executed on a PC running an E-Prime 2.0 program (Psychology Software Tools) that controlled stimulus presentation.

Design. The experiment had a 2 (deviant: no deviant vs. deviant) × 2 (task-difficulty: low vs. high) within-participant design. There were 90 trials divided into two blocks: one block with female-spoken irrelevant sequences, and in which the deviant was therefore a male-spoken letter, and another with male-spoken irrelevant sequences and female-spoken deviants. Each block comprised 39 "no deviant" trials and six "deviant" trials. A deviant occurred on Trials 5, 8, 18, 27, 35, and 41 within each block. Half of the to-be-remembered lists were presented using the nondegraded stimuli (low task-difficulty lists), whereas the other half were presented using the perceptually degraded stimuli (high task-difficulty lists). Within each block, low and high task-difficulty to-be-remembered lists were assigned to trials in a random order, with the constraint that there were no more than three consecutive runs of each list-type. The two blocks were administered without a pause, and their order was counterbalanced across participants.

Procedure. Following the final to-be-remembered item, participants were to recall the list in forward serial order by writing each item, from left to right, in one of eight locations on a response sheet, where each location represented a position in the sequence. They were instructed to provide a response at each position, and they could guess if unsure but they were also permitted to record a dash (-) if they could not recall a given item. The recall interval was 15 s and, upon completion, the next trial commenced automatically. To alert participants that the next to-be-remembered list was imminent, a 500 ms tone sounded 2 s before the recall interval expired. Participants were informed that the irrelevant speech sounds were irrelevant to the recall task, and that they should ignore it as best as they could. There were two practice trials performed in quiet prior to the first block of experimental trials. The experimental session lasted approximately 40 min.

Results

In all experiments reported in this article, the raw data were scored using the standard strict serial recall criterion: An item was only recorded as correct if its recall serial position was the same as its presentation serial position. Effect size estimates for focused comparisons are provided for all experiments using Pearson's correlation coefficient *r* (cf. Rosenthal & DiMatteo, 2001). Figure 2 shows recall performance collapsed across serial position as a function of task-difficulty and deviation. The results are clear-cut: Under low task-difficulty, the presence of a voice-deviant in the irrelevant auditory sequence markedly impairs serial recall (replicating previous studies; e.g., Hughes et al., 2007); the novel aspect of the results, however, is that under high task-difficulty, this effect is eliminated.

Statistical support for this pattern was obtained from a 2 (deviant: no deviant vs. deviant) × 2 (task-difficulty: low vs. high) analysis of variance (ANOVA). There was a main effect of deviant, $F(1, 26) = 18.41$, $MSE = 0.073$, $p < .001$, $r = .64$, and a main effect of task-difficulty, $F(1, 26) = 19.32$, $MSE = 0.071$, $p < .001$, $r = .65$. Critically, there was a significant task-difficulty × deviant interaction: $F(1, 26) = 15.50$, $MSE = 0.059$, $p < .01$, reflecting the fact that, under low task-difficulty, serial recall performance was poorer on "deviant" than "no deviant" trials, $t(26) = 6.56$, $p < .001$, $r = .44$, whereas this difference was not apparent under high task-difficulty, $t(26) = .28$, $p = .784$, $r = .02$.

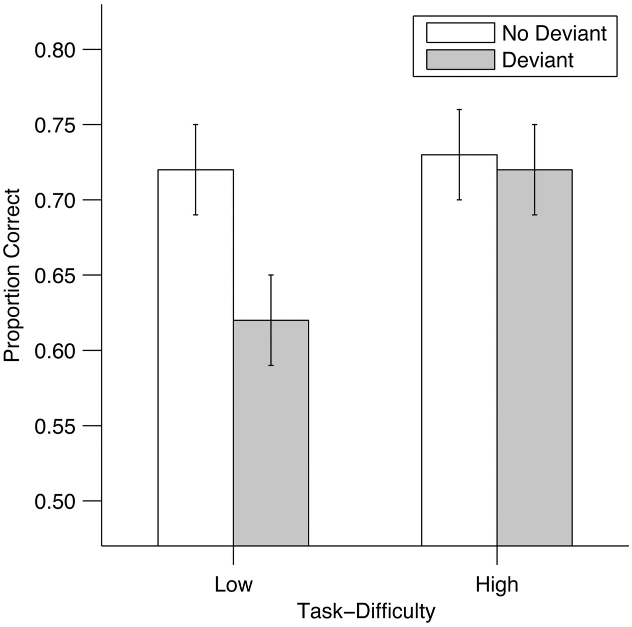

Figure 2. Proportion of correct responses for "no deviant" and "deviant" trials in the low task-difficulty and high task-difficulty conditions of Experiment 1. Error bars represent the standard error of the mean.

Discussion

Experiment 1 established that attentional capture by a deviation within a sound sequence during serial recall (cf. Hughes et al., 2007) is abolished when the visually presented focal material is relatively difficult to encode.[1] One way to account for this result is in terms of a top-down modulation of the allocation of selective attention: In response to the degraded task conditions, the level of task-engagement is actively increased such that the deviant loses its usual power to disengage attention from the task at hand. This account harmonizes nicely with the finding that individuals high in working memory capacity—associated typically with increased ability to actively maintain task-goal representations in a highly accessible state (Kane & Engle, 2003)—are less susceptible to the deviation effect (Sörqvist, 2010).

However, the consistency between the effects of high task-difficulty and high working memory capacity on the impact of a deviant does not necessarily imply that these effects share a common mechanism. Whereas the attenuation of the deviation effect due to high working memory capacity is clearly a top-down effect, it could be argued that the effect of high task-difficulty in Experiment 1 was, instead, the result of a passive, bottom-up, form of distraction-control. Specifically, rather than being driven by a shift in top-down cognitive control settings in response to increased task difficulty, the greater perceptual processing demand itself may have exerted a bottom-up constraint on the capacity to process the deviant. Indeed, according to the *perceptual load model* of attention (Lavie & Tsal, 1994), the control of selective attention is, in part, a passive by-product of the perceptual load imposed by a focal task. This model assumes that there is a limited attentional resource specifically dedicated to perceptual processing. Thus, if performing the focal task exhausts this resource, the power of any irrelevant stimuli to distract is reduced simply because they are not perceived; they are “filtered out” passively (Lavie, 2005). On this model, increased perceptual load occurs, for example, when “perceptual identification is more demanding on attention” (Lavie, 2005, p. 75). Thus, it is plausible that the increased task-difficulty in Experiment 1 may be conceptualized as an increase in perceptual load. Indeed, Yi et al. (2004), who found an attenuation of fMRI-indexed processing of irrelevant (visual) stimuli when target face stimuli were embedded in static visual noise, referred to their degradation manipulation as one of perceptual load, and they interpreted their findings in terms of the perceptual load model. According to this perspective, the increased task-difficulty in Experiment 1 led to a bottom-up filtering of the sound sequence, thus, presumably making the deviant less detectable, rather than reflecting an active, internally driven, increase in task-engagement. Given this ambiguity, in Experiment 2 we sought to demonstrate top-down modulation of the deviation effect without changing any intrinsic (“bottom-up”) features of the task-setting (e.g., degraded stimulus conditions).

Experiment 2

In Experiment 2, we capitalize on recent evidence suggesting that task-disengagement due to a deviant is the result of the deviant’s violation of expectancies based on the invariance characterizing the preceding sequence of stimuli (Parmentier, Elsley, Andrés, & Barcelo, 2011; Vachon et al., 2012). It is reasonable, therefore, to expect that the maintenance of task-engagement, despite the presence of a deviant, could be promoted by allowing participants to anticipate that deviant. In Experiment 2, therefore, we influenced participants’ expectations—clearly a top-down factor—by providing them (or not) with a (100% valid) warning before each trial as to whether or not the ensuing irrelevant sound sequence contained a deviant. Such foreknowledge should presumably afford the opportunity to actively incorporate the deviant into a forward (predictive) model of the imminent sound sequence (Vachon et al., 2012; Winkler, Denham, & Nelken, 2009) such that, in effect, the physical deviation would no longer constitute a cognitive violation. A possibly related effect was reported by Sussman, Winkler, and Schröger (2003): They found that the time taken to categorize each of a succession of tones (as short or long) was less impaired by the presence of a rare deviation in the frequency of the tone if the deviation was signaled by a visual cue. They concluded that “determining the relevance of a sound prior to its occurrence can suppress the involuntary orienting of attention, which could conserve attentional resources for the task of relevance to the organism” (Sussman et al., 2003, p. 636). However, an important difference between the present setting and that studied by Sussman et al. (2003; see also Horváth & Bendixen, 2012) is that in the latter case the deviation occurred on a dimension of the to-be-attended target sound. To our knowledge, only one study has addressed whether a warning influences auditory distraction when attention is not already directed toward the auditory modality: Shelton, Elliott, Eaves, and Exner (2009) found that, following distraction by a cell phone ring (presented in the context of an otherwise quiet background), performance of a visually presented lexical-decision task recovered more quickly if participants were warned that there would be a cell phone ring at some point during the experimental session. However, here we were interested in whether a warning (manipulated in this case on a trial-by-trial basis) would have the capacity to reduce auditory attentional capture itself, rather than facilitate recovery from the capture effect.

Another novel feature of the current experiment was that we factorially combined a manipulation of foreknowledge with the same manipulation of task-difficulty implemented in Experiment 1 so as to independently evaluate the impact of each factor within the same experiment. An outcome whereby foreknowledge exerts a comparable effect to high task-difficulty would militate against the idea that the perceptual load model (Lavie, 2005) provides a comprehensive alternative account of the resistibility of the deviation effect.

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[1] At first glance, this result seems to contradict that of Parmentier et al. (2008), who used the same degradation manipulation in the context of a reaction-time based crossmodal oddball task. They found no reduction of distraction by a deviant tone when presented prior to a to-be-categorized digit (e.g., as odd or even). However, in that case, the deviant may have captured attention (and hence had the power to disrupt performance) before the degraded status of the visual stimulus was able to induce greater task-engagement. In contrast, in the list-based task used here, even though the deviant was again presented shortly before a visual item (the fifth item), the degradation of earlier items in the list is likely to have already acted to promote task-engagement before the deviant was presented.

Method

Participants, apparatus, and materials. Twenty-four Cardiff University students took part in the experiment in return for payment of £10. All reported normal hearing and normal or corrected-to-normal vision. The apparatus and materials were the same as in Experiment 1.

Design. The experiment employed a 2 (warning: no warning vs. warning) × 2 (deviant) × 2 (task-difficulty) within-participant design. Warning condition was blocked, and it was counterbalanced across participants. Each block consisted of 80 "no deviant" trials (40 low task-difficulty trials and 40 high task-difficulty trials) and 12 "deviant" trials (six low task-difficulty trials and six high task-difficulty trials), making 184 trials in all. In one block, the deviant sequences occurred on Trials 10, 21, 24, 33, 38, 45, 55, 66, 69, 78, 83, and 90, whereas in another block they occurred on Trials 5, 8, 18, 27, 35, 41, 50, 53, 63, 72, 80, and 86. These two deviant-trial schedules were rotated over the "no-warning" and "warning blocks". The to-be-ignored auditory sequences were always presented in a female voice, with deviants presented in a male voice (there was evidence from Experiment 1 that voice of presentation was not a significant factor; see also Vachon et al., 2012).

Procedure. The procedure was similar to Experiment 1, with the following exceptions. First, the trials were self-paced rather than controlled by the computer to ensure that the warning cues in the warning block would not be missed (see below). In the "without-warning" condition, a box containing the words "Begin Trial" presented in black font appeared in the central screen position at the start of the trial, and participants had to select the box using the mouse-controlled pointer to commence the trial. In the "warning" condition, this box contained the message "No Deviant" presented in black font on the "no deviant" trials, whereas the message "Deviant" was presented in red font on the "deviant" trials. In order to make the conditions more distinctive, on the "deviant" trials only, once the box had been selected, the warning message flashed off (500 ms), and then back on (500 ms) again, on three occasions prior to presentation of the imminent trial. Second, to expedite written-response transcription time at the data analysis stage, the output-mode on this occasion involved using a mouse-controlled pointer to indicate the order of the just-presented digits (see, e.g., Jones, Hughes, & Macken, 2006): Following the final to-be-remembered item, nondegraded versions of the digits were re-presented at random positions within a circular array beneath which there were eight response boxes corresponding to the eight positions in the to-be-remembered list. Participants were required to reproduce the to-be-remembered list in forward serial order by selecting the digits using the mouse-driven pointer. Once a digit was selected, it disappeared for 50 ms before reappearing, and a copy of the digit appeared in the response window corresponding to the current recall position. Because items remained in the circular array once selected, repetitions of the same item were possible, as with written recall. If participants were unsure of the correct item at a given recall position, they could either guess or they could click on a "?" button in the center of the array in order to record a "don't know" response. To preview the results, the impact of high task-difficulty found in Experiment 1 was replicated in this experiment indicating that the change in output-mode is unlikely to have a bearing on the interpretation of any impact of warning.

The "no warning" and "warning" blocks, each lasting approximately 50 min, were administered on separate days given the taxing nature of the serial recall task. Participants were given four practice trials before each block: In the "no warning" block, these consisted of two low task-difficulty and two high task-difficulty, "no deviant" trials, whereas in the "warning" block, these consisted of two low task-difficulty trials, comprising a single "no deviant" trial and a single "deviant" trial, and two high task-difficulty trials also comprising a single "no deviant" trial and a single "deviant" trial. Finally, in the "warning" condition, participants were informed that on "deviant" trials they should "try hard to ignore the voice-deviant in the irrelevant auditory sequence."

Results

Figure 3 shows serial recall performance in the "no warning" (left panel) and "warning" (right panel) conditions. First, replicating the results of Experiment 1, in the absence of a warning, the presence of a voice-deviant in the irrelevant auditory sequence impaired serial recall performance under low but not high task-difficulty. However, the novel finding is that the voice-deviant effect observed under low task-difficulty was also abolished (regardless of task-difficulty) by the provision of a warning about the imminent deviant (right panel).

This impression of the data was confirmed by a 2 (warning) × 2 (deviant) × 2 (task-difficulty) ANOVA. The main effect of warning was not significant, $F(1, 23) = 1.15$, $MSE = 0.023$, $p = .295$, $r = .22$, but there was a significant main effect of deviant, $F(1, 23) = 8.47$, $MSE = 0.069$, $p < .01$, $r = .52$, and a significant main effect of task-difficulty, $F(1, 23) = 5.731$, $MSE = 0.032$, $p < .05$, $r = .45$. There was also a significant warning × deviant interaction, $F(1, 23) = 6.78$, $MSE = 0.023$, $p < .05$, a significant warning × task-difficulty interaction, $F(1, 23) = 4.66$, $MSE = 0.019$, $p < .05$, and, crucially, a significant warning × deviant × task-difficulty three-way interaction, $F(1, 23) = 5.04$, $MSE = 0.016$, $p < .05$. To scrutinize the three-way interaction further, two separate 2 (task-difficulty) × 2 (deviant) ANOVAs were performed, the first on the data for the "no warning" condition, and the second on the data for the "warning" condition. For the "no warning" condition, there was a significant main effect of deviant, $F(1, 23) = 16.92$, $MSE = 0.085$, $p < .001$, $r = .65$, and a significant main effect of task-difficulty, $F(1, 23) = 12.15$, $MSE = 0.050$, $p < .01$, $r = .59$, as well as a significant interaction between the two factors, $F(1, 23) = 9.74$, $MSE = 0.032$, $p < .01$, which arose because, under low task-difficulty, performance was worse on "deviant" than "no deviant" trials, $t(23) = 4.86$, $p < .001$, $r = .71$, whereas, under high task-difficulty, there was no such difference, $t(23) = 0.59$, $p = .201$, $r = .12$. For the "warning" condition, no main effects or interactions were significant ($F < 1$ in all instances), confirming that the provision of a warning about the presence of an imminent voice-deviant eliminated the deleterious effect of that deviant usually found under low task-difficulty.

Discussion

Experiment 2 provides further evidence for top-down control of auditory attentional capture: Providing foreknowledge about an

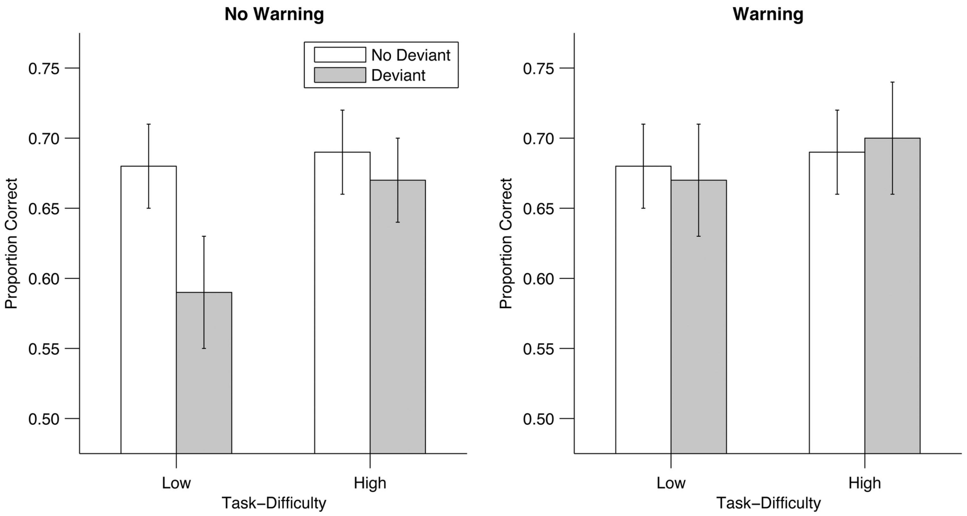

Figure 3. Proportion of correct responses for "no deviant" and "deviant" trials under low and high task-difficulty for the "no warning" (left panel) and the "warning" (right panel) conditions of Experiment 2. Error bars represent the standard error of the mean.

imminent voice-deviant eliminated its disruptive impact on serial recall. This extends previous observations of a reduction in distraction by an auditory deviation given the provision of a warning cue (Sussman et al., 2003) to an intermodal paradigm in which the sound is irrelevant to current behavior. The result also indicates that foreknowledge can, in certain settings at least, eliminate the attentional capture effect itself rather than only helping the recovery of performance following a capture effect (Shelton et al., 2009). Furthermore, foreknowledge and high task-difficulty each, independently, eliminated the deviation effect. These results—especially when viewed in light of previous research showing that individuals with high working memory capacity are less susceptible to the deviation effect (Sörqvist, 2010)—tend to favor the view that both the effect of high task-difficulty and that of foreknowledge reflect the sensitivity of the deviation effect to top-down influences. The notion that the impact of task-difficulty is a different, bottom-up, effect resulting from high perceptual load (cf. Lavie, 2005) seems less parsimonious (see also Experiment 3a).

Experiments 1 and 2 have advanced the characterization of attentional capture by a deviant using sharply different methods. Now, we turn to test the second key prediction of the duplex-mechanism account, namely, that disruption of serial recall by changing-state sequences (e.g., "k g m q . . ." compared to a steady-state item, e.g., "k k k k . . ."; Jones et al., 1992), as opposed to a single deviant sound, should not be so influenced by top-down factors designed to facilitate task-engagement such as high task-difficulty or foreknowledge of imminent distraction. This follows from the duplex-mechanism account's supposition that the changing-state effect is a joint product of the changing nature of the sound and the specific, serial rehearsal, process typically deployed to support serial recall (interference-by-process; Jones & Tremblay, 2000) rather than reflecting disengagement from the task. Finding that the changing-state effect is immune to the factors that reduce the deviation effect would also further undermine a single-mechanism approach in which both phenomena are driven by attentional capture (e.g., Chein & Fiez, 2010; Cowan, 1995).

Experiment 3a

In Experiment 3a, we test whether the changing-state effect is immune to the same increase in task-difficulty that attenuated the deviation effect in Experiments 1 and 2. Note that there was no evidence from those experiments that degradation of the digits precluded serial rehearsal of the list, the key precondition for the changing-state effect according to the duplex-mechanism account. Had this been the case, it would have been reasonable to expect high task-difficulty, contrary to the data, to have a direct effect on serial recall as occurs, for example, when rehearsal is impeded under conditions of articulatory suppression where participants are required to repeat an irrelevant utterance during list presentation (Baddeley, 2007; Jones, Macken, & Nicholls, 2004). Thus, on the duplex-mechanism account, the changing-state effect should not be influenced by item degradation.

In contrast, single-mechanism accounts in which the changing-state effect, like the deviation effect, is attributed to attentional capture, predict that high task-difficulty should also attenuate the changing-state effect. For example, within this approach, it has been suggested that the finding that the changing-state effect is smaller when the sound is presented during the presentation of the to-be-remembered items compared with during a postpresentation retention interval (e.g., Chein & Feiz, 2010; Macken, Mosdell, & Jones, 1999) may be explained in terms of increased task-engagement: "the physical presence of memorial stimuli during presentation may be sufficient to hold the focus of attention in place and thus limit orienting toward irrelevant stimuli" (Chein & Fiez, 2010, p. 132). According to this logic, increasing the difficulty of encoding through item degradation—shown in Experiments 1 and 2 to be particularly effective in terms of preventing task-disengagement—should be especially effective also at reducing the changing-state effect.

Experiment 3a also provides a second convergent test of the perceptual load model-based account (cf. Lavie, 2005) of the impact of high task-difficulty found in Experiments 1 and 2. It has been shown that if a changing-state sound sequence is low-pass filtered—thereby reducing the perception of changes in the sound—its disruptive effect is diminished in a monotonic fashion as a function of the degree of filtering (Jones, Alford, Macken, Banbury, & Tremblay, 2000). Thus, if our high focal task-difficulty condition constitutes a high perceptual load that serves to filter out the processing of an irrelevant sound sequence, it seems reasonable to expect that *any* form of distraction that results from the presence of that sequence—including the changing-state effect—should be reduced under high task-difficulty.

Method

Participants, materials and apparatus. Forty-five Cardiff University psychology students took part in the experiment in return for course credits. All reported normal hearing and normal or corrected-to-normal vision.

The materials were the same as those employed in Experiment 1 except that the irrelevant items were always conveyed in the female voice. Two types of irrelevant auditory sequences were created: In "steady state" sequences, a single letter, chosen at random for each sequence, was repeated 10 times, whereas in "changing state" sequences, all 10 letters were presented in a different random order for each sequence.

Design and procedure. The experiment employed a 2 (state: steady vs. changing) × 2 (load) within-participant design. There were 60 trials presented in a single block within which steady-state (30 trials) and changing-state irrelevant sound sequences (30 trials) varied randomly from trial to trial. Half of the to-be-remembered sequences were presented using the nondegraded stimuli, whereas the other half were presented using the perceptually degraded stimuli. These low task-difficulty and high task-difficulty to-be-remembered lists were assigned to trials in a fixed but random order, with the constraint that there were no more than three consecutive runs of each trial-type. Participants completed two practice trials in quiet before commencing the experiment proper, and the procedure was identical to that employed in Experiment 1.

Results and Discussion

The left panel of Figure 4 shows serial recall accuracy for the two sound conditions according to task-difficulty. It is clear that performance was poorer in the presence of changing-state compared to steady-state irrelevant sound sequences, thereby replicating the classical changing-state effect. Of greater note, however, the magnitude of the changing-state effect, in contrast to the deviation effect, was not modulated by task-difficulty.

A 2 (state: steady vs. changing) × 2 (task-difficulty: low vs. high) ANOVA revealed a significant main effect of state, $F(1, 44) = 102.097$, $MSE = .675$, $p < .0001$, $r = .84$, but neither the main effect of task-difficulty, $F(1, 44) = .351$, $MSE = .001$, $p = .556$, $r = .09$, nor the interaction between task-difficulty and state were significant, $F(1, 44) = .14$, $MSE = .000$, $p = .71$.

Experiment 3a established that the impact of continuously changing stimuli as compared with a steady-state stimulus (Jones et al., 1992) is, in contrast to the impact of a single deviant sound (cf. Experiments 1 and 2), immune to modulation by high task-difficulty suggesting that the changing-state effect is relatively insensitive to top-down influences. Before further discussion, however, in Experiment 3b we sought first to bolster this view by examining whether the changing-state effect is also, unlike the deviation effect (cf. Experiment 2), immune to the influence of foreknowledge of the nature of the sound sequence.

Experiment 3b

In this experiment, we tested the hypothesis that unlike foreknowledge of an imminent deviant sound (cf. Experiment 2), foreknowledge of an imminent changing-state sequence (as opposed to a steady-state sequence) will be ineffectual in terms of

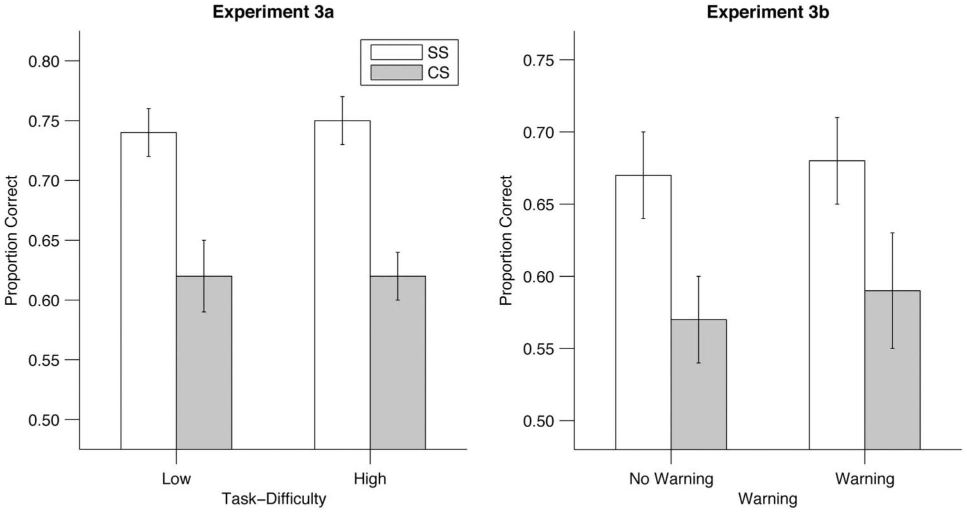

Figure 4. Proportion of correct responses for steady state (SS) and changing state (CS) sound sequences for the low task-difficulty and high task-difficulty conditions of Experiment 3a (left panel) and the without- and with-warning conditions of Experiment 3b (right panel). Error bars represent the standard error of the mean.

reducing the changing-state effect. The design was similar to Experiment 2 except we omitted the task-difficulty manipulation given that Experiment 3a has already established that task-difficulty has no impact on the changing-state effect; thus, we manipulated only the presence or not of a warning about the nature of the imminent irrelevant sound sequence. Moreover, given that we were interested in this experiment in the possible effect of top-down knowledge relating to the predictability of encountering a particular type of sound sequence, in both the “no warning” and “with warning” block, the ratio of changing-state to steady-state trials (1:4) was equivalent to the ratio of “with deviant” to “no deviant” trials used in Experiment 2. On any account that construes the changing-state effect as a “multiple-deviant effect” (e.g., Chein & Fiez, 2010; Cowan, 1995), it seems reasonable to suppose that the greater (indeed perfect) predictability of encountering these “deviants” in the “with warning” block should reduce or eliminate their disruptive potency as was the case with a single deviant (Experiment 2).

Method

Participants, materials, and apparatus. Thirty-one individuals recruited from the campus community at Cardiff University took part in the experiment in return for payment of £10. All reported normal hearing and normal or corrected-to-normal vision. The apparatus and materials were the same as those employed in Experiment 3a, except that the to-be-remembered lists were always conveyed using the nondegraded digit stimulus ensemble (i.e., low task-difficulty).

Design and procedure. A 2 (warning) × 2 (state) within-participant design was used where warning condition was blocked and counterbalanced across participants. Each block consisted of 80 steady-state trials and 12 changing-state trials. In one block, the changing-state sequences occurred on Trials 10, 21, 25, 28, 43, 50, 54, 65, 84, 88, 94, and 97, whereas in the other block they occurred on Trials 12, 23, 26, 32, 41, 48, 52, 66, 69, 72, 83, and 98. These two changing-state trial schemes were rotated over the “no-warning” and “warning” blocks. The procedure was the same as that employed in Experiment 2, except that in the “warning” block, a box containing the message “Steady State” was presented in black font at the start of steady-state sound trials, whereas the message “Changing State” was presented in red font at the start of changing-state sound trials. When participants initiated a changing-state trial in this block, the warning message flashed off-and-on three times. In the “warning” block, participants were instructed that, on changing-state trials, they “should try hard to ignore the changes in sound in the irrelevant auditory sequence.” The “no warning” and “warning” blocks each took approximately 50 min to complete, they were administered on separate days, and they were each preceded by a single steady-state and changing-state practice trial.

Results

It is clear from the right panel of Figure 4 that whereas the changing-state effect was again replicated, warning had no impact. A 2 (warning) × 2 (state) ANOVA revealed a significant main effect of state, $F(1, 30) = 49.315$, $MSE = 1.977$, $p < .0001$, $r = .79$, but the main effect of warning was not significant, $F(1, 30) = .736$, $MSE = 0.068$, $p = .398$, nor, critically, was the two-way interaction, $F(1, 30) = .027$, $MSE < 0.0001$, $p = .871$.

Discussion

Experiments 3a and 3b showed that in contrast to the impact of a single deviant sound, the effect of a continuously changing-state sequence is not modulated either by increased task-difficulty (Experiment 3a) or by foreknowledge of the nature of the imminent auditory sequence (Experiment 3b). These results are consistent with our contention that the deviation effect, but not the changing-state effect, results from a disengagement of attentional selectivity from the focal task: Factors designed to promote such engagement eliminate the former but not the latter form of auditory distraction. At first glance, this conclusion seems at odds with the finding that the changing-state effect is smaller when the sound is presented during the encoding of to-be-remembered stimuli as opposed to during a postlist retention interval; a straightforward explanation for this finding is that having to encode the visual stimuli facilitates task-engagement (Chein & Fiez, 2010). However, the interference-by-process account can also explain this finding by supposing that the burden on serial rehearsal is generally greater during the retention interval when the entire list has been encoded than during presentation when the burden on rehearsal only starts to become great once four or five items have been encoded (see Macken et al., 1999).

The results of Experiment 3b are also problematic for attentional capture accounts of the changing-state effect on the grounds that, on this approach, one would have expected the effect, in the no-warning block, to be particularly strong given that the stimuli used for the changing-state sequences were both relatively rare and unexpected in the context of the overall block of trials (given the ratio of 4:1 of steady- compared to changing-state trials). There is no evidence that this was the case: Changing-state stimuli appear to produce no more disruption than when they are encountered far more frequently across a block of trials (i.e., in the context of the 1:1 ratio of steady- compared to changing-state trials used in Experiment 3a; see also Tremblay & Jones, 1998).

Furthermore, the results of Experiment 3a, in particular, militate further against the alternative notion that the elimination of auditory attentional capture under high task-difficulty observed in Experiments 1 and 2 is a passive by-product of an increase in perceptual load (cf. Lavie, 2005): This account cannot readily explain why both forms of distraction were not modulated in a similar way by the same increase in task-difficulty.

Analysis of the Relation of Working Memory Capacity to the Two Forms of Auditory Distraction

It was noted in the Introduction that there are robust individual differences in the ability to maintain task-engagement, as indexed by classic measures of working memory capacity such as OSPAN (Turner & Engle, 1989). In line with the duplex-mechanism account (Hughes et al., 2007) and with the results reported in the present article, previous evidence suggests that whereas there is no relationship between working memory capacity and the changing-state effect (e.g., Beaman, 2004; Sörqvist, 2010), there is indeed a (negative) relationship between working memory capacity and susceptibility to the deviation effect (Sörqvist, 2010). However, given our repeated appeal in this article to this dissociation and the fact that it rests currently on a single report (Sörqvist, 2010), it seemed worthwhile corroborating it here and, within a single study, to potentially show a convergence of psychometric and experimental support for the differential cognitive controllability of the two forms of auditory distraction.[2]

Method

The participants from Experiments 2 and 3b—prior to partaking in their respective serial recall sessions—were presented with a computerized version of the OSPAN (Turner & Engle, 1989). For brevity, we only sketch out here the key features of the task; a complete description can be found in Unsworth, Heitz, Schrock, and Engle (2005), who describe the computerized instantiation of OSPAN on which our task is based. Participants were presented with visual lists of letters (sampled at random from the set: *F*, H, J, K, L, N, P, Q, R, S, T, and Y) for subsequent serial recall. Each letter was followed by a mathematical operation [e.g., $(5 + 4) \times 2 = ?$] that the participant had to solve as quickly and as accurately as possible. As soon as the participant solved the operation, they clicked the mouse and a solution was displayed on-screen. The participant was then required to indicate whether the given solution to the operation was correct, or not, by clicking the mouse on a "True" or "False" icon displayed on-screen. After responding, the next letter was presented, followed by another mathematical operation, and so on. Once all the list-items had been presented, the letters were displayed at random positions in a 4 × 3 spatial array, and participants were required to click on the letters presented in forward serial order using the mouse. The list-length—and hence the number of intervening mathematical operations—varied from three to seven. There were three trials for each list-length, and lists were administered in a different random order for each participant. Before commencing the task proper, participants received a set of practice trials in which they engaged in the serial recall task only, followed by practice trials in which they solved mathematical operations only, before finally engaging in practice trials in which the serial recall and mathematical operations were combined. The task was scored using an "absolute OSPAN" scoring method (Unsworth et al., 2005), calculated by summing the number of correct responses on those lists in which items were recalled with 100% accuracy.

Results and Discussion

The participants' OSPAN scores were correlated both with their susceptibility to disruption by a deviant (i.e., participants in Experiment 2) and to disruption by a changing-state sequence (i.e., participants in Experiment 3b).

Susceptibility to the deviation effect was operationalized as the proportion of items correctly recalled on no-deviant trials minus the proportion recalled on deviant trials within the "low-load, no warning" condition of Experiment 2. The 24 participants' difference scores were then correlated with their OSPAN scores. Figure 5, left panel, shows the resulting scatter-plot. There is a clear (negative) relationship between OSPAN scores and susceptibility to the deviation effect. This was corroborated statistically in the form of a significant negative correlation, $r(22) = -.38, p < .05$. Turning to the changing-state effect, susceptibility to this effect was operationalized as the proportion of items correctly recalled on steady-state trials minus the proportion recalled on changing-state trials in Experiment 3b regardless of warning condition (given that warning had no influence on the changing-state effect). The OSPAN scores were not correlated with susceptibility to the changing-state effect, $r(29) = .046$, $p = .404$ (cf. right panel of Figure 5).

Our analysis of the impact of individual differences in working memory capacity on the two forms auditory distraction is entirely in line with previous studies (Beaman, 2004; Ellermeier & Zimmer, 1997; Elliott & Cowan, 2005; Neath et al., 2003; Sörqvist, 2010). Moreover, it is noteworthy that the effects of high working memory capacity and the impact of our experimental manipulations on the deviation effect (Experiments 1 and 2) resonate with similar conclusions based on visual distraction using the Stroop paradigm: Kane and Engle (2003) argued that one aspect of Stroop performance is a failure to actively maintain the task-goal ("name the color") in the face of strong but response-inappropriate bottom-up influences (the content of the word). They found that external factors that facilitate task-goal maintenance such as having a high proportion of incongruent color-word pairs (such pairs providing a constant reminder of the task-goal) as opposed to a high proportion of congruent color-word pairs allow individuals with low working memory capacity to perform as well as those with high working memory capacity. The same appears to be the case here: When task-engagement is aided by external influences (high task-difficulty, warning cues), those with low as well as high working memory capacity are able to attenuate the deviation effect, whereas those with high working memory capacity are less reliant on such external aids (see also Hutchison, 2007, 2011).

General Discussion

To summarize the key results of the current series, Experiment 1 showed that the disruptive effect of a single deviant within a task-unrelated auditory sequence on a visually presented focal task (serial recall) was attenuated when the difficulty of encoding the visual task-relevant stimuli was increased by reducing their perceptual discriminability. Experiment 2 showed that a forewarning about a deviant—clearly a top-down factor—had a comparable effect to high task-difficulty. This suggests a shared identity for the effects of high task-difficulty and foreknowledge as ones related to top-down task-engagement, contrary to the view that the impact of the former may have arisen due to high perceptual load, and hence constitute a bottom-up form of distraction-control (see Lavie, 1995, 2005). In Experiments 3a and 3b, we tested the view that whereas attentional capture by a deviant may be open to the influence of top-down factors, another form of auditory distraction is not: We found that the deleterious effect on serial recall of a continuous sequence of changing sounds was immune to either

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[2] Note that it is the requirement to simultaneously carry out the unrelated processing component of OSPAN (i.e., verifying the validity of the operations) and the serial recall component (i.e., remembering the letters) that endows it with the utility to predict both higher-order (e.g., language comprehension) and lower-order attentional capacities (e.g., antisaccade performance). This is why we did not simply correlate performance on the serial recall task (i.e., "simple span") used in Experiments 2 and 3b with susceptibility to the two forms of distraction.

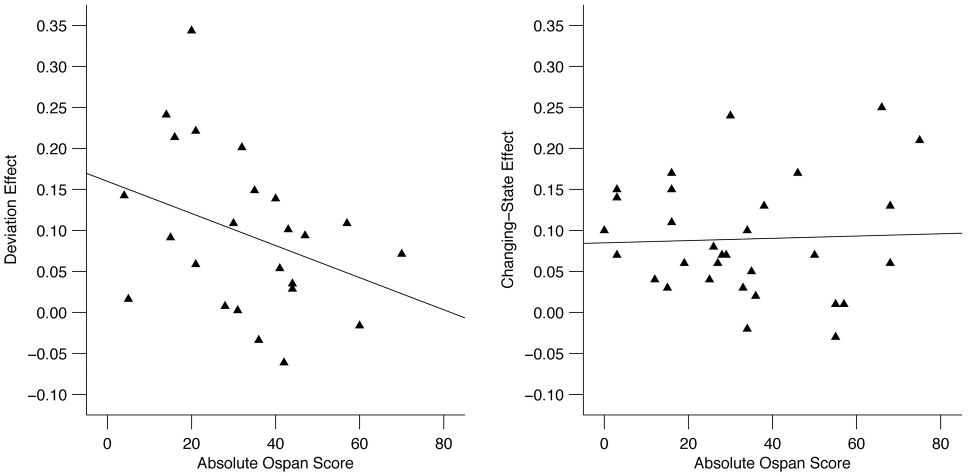

Figure 5. Scatterplots showing the negative relationship between working memory capacity (as measured by OSPAN) and susceptibility to the deviation effect (left panel) and the absence of such a relationship between working memory capacity and susceptibility to the changing-state effect (right panel).

increased focal task-difficulty or foreknowledge of the nature of the imminent auditory sequence.[3] Finally, we provided convergent psychometric evidence for the dissociation between the two forms of auditory distraction by corroborating the observation that individual differences in working memory capacity—commonly associated with differences in the ability to maintain engagement on a focal task—correlate negatively with susceptibility to the deviation effect but not the changing-state effect (e.g., Sörqvist, 2010).

Support for the Duplex-Mechanism Account of Auditory Distraction

The present study is the first to our knowledge to provide experimental (as well as psychometric) evidence for a dissociation between two forms of auditory distraction in terms of their amenability to top-down control: While attentional capture by a deviant can be resisted, disruption by continuously changing sounds is indomitable. This provides strong support for the view that the changing-state effect operates via a different mechanism from the deviation effect. Note that even if we were to concede that our task-difficulty manipulation may have acted, at least in part, to increase focal task-engagement through bottom-up processes (due to high perceptual load; e.g., Lavie, 2005), this does not alter the fact that this single manipulation (as well as that of foreknowledge) dissociated the two effects, thereby lending support to the duplex-mechanism account (Hughes et al., 2007).

Contrary to a single-mechanism approach (e.g., Bell et al., 2010; Chein & Fiez, 2010; Elliott, 2002), we have suggested that the changing-state effect is better explained by interference-by-process rather than attentional capture: The obligatory processing of order cues yielded by a succession of changing sounds (but not by a single repeated item) competes specifically with the process of maintaining the order of the to-be-remembered items (or serial rehearsal; Jones & Macken, 1993). There is no reason to suppose that high task-difficulty or foreknowledge of potential distraction would have prevented the adoption of a serial rehearsal strategy, hence the prerequisite for the changing-state effect remained. While the present experiments were not designed to provide further direct evidence for this interference-by-ordering-process account, it enjoys ample support from previous studies: For example, the changing-state effect is not found in tasks that do not involve or encourage a serial rehearsal strategy (e.g., Beaman & Jones, 1997; Hughes et al., 2007), nor is it found if participants are prevented from engaging in serial rehearsal by being instructed to engage in articulatory suppression (Jones et al., 2004).

Our argument that the changing-state effect is not caused by attentional capture may seem counterintuitive, that is, why should a succession of changing stimuli such as that used in a typical changing-state sequence not capture attention? The answer to this question, we suggest (see also Hughes et al., 2007; Vachon et al., 2012), is that the notion that changing-state stimuli should capture attention is based on an incorrect view of the precondition for auditory attentional capture. The notion is a corollary of the idea that the key precondition is stimulus novelty (or "newness"): In a changing-state sequence (unlike a steady-state sequence), each successive item is novel or new and hence captures attention. However, such a novelty-detection account has been found wanting. In terms of the properties of the sound sequence (that is, regardless of any other factors), novelty is neither a necessary nor sufficient precondition for auditory attentional capture. For example, the repetition of a stimulus (e.g., *B*) can capture attention following its regular alternation with another stimulus

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[3] The differential influence of high task-difficulty, foreknowledge, and high working memory capacity on the two forms of auditory distraction cannot be explained in terms of differences in the initial strength of the two effects: Both the changing-state effect and the deviation effect (in baseline conditions) produced similar increases in error rate (ranging between a 9 and 12% increase). More tellingly, within this small range, the likelihood of attenuation of an effect was not a function of effect-strength: For example, the changing-state effect in Experiment 3b was slightly smaller (9%) than the deviation effect in Experiment 2 (10%), and yet the latter but not former effect was eliminated by a warning.

(ABABAB*B*; e.g., Hughes et al., 2007; Nordby, Roth, & Pfefferbaum, 1988); here, then, a stimulus appears to capture attention precisely because it is not new. Conversely, a stimulus that is novel can fail to capture attention if the stimulus is expectable (e.g., the "6" in "1 2 3 4 5 6"; Velden, 1978). These types of observations indicate that the precondition for auditory attentional capture is not novelty but, as noted earlier, expectancy violation (see Parmentier et al., 2011; Vachon et al., 2012). On this account, a changing-state sequence should have no more power than a steady-state sequence to capture attention because none of the stimuli in either type of sequence violates an expectation (for further discussion, see Hughes et al., 2007).

Two Forms of Distraction—Two Forms of Control?

The present findings suggest that the changing-state effect, unlike the deviation effect, is not amenable to control through increased focal-task engagement. However, this is not to say that changing-state sequences encountered during serial recall are not subject to any type of control mechanism. We have argued that the control of distraction in the present study (i.e., in the case of the deviation effect) was imposed by increasing task-engagement. However, it is commonly assumed that another form of top-down control is direct inhibition of the distracting material itself (e.g., Tipper, 1985, 2001). There is evidence that in cases of interference-by-process, such as indexed by the changing-state effect, the sound is indeed subject to such direct inhibition: Hughes and Jones (2003a) found that, under certain conditions, a to-be-remembered list of (visually presented) digits was particularly poorly recalled if that same sequence was presented as an irrelevant sound sequence on the previous trial. This negative priming-type effect (cf. Tipper, 2001) was taken to suggest that direct inhibition of the irrelevant sequence was carried over such that it impaired recall of that same sequence on the subsequent trial. However, even if changing-state sequences are inhibited, they nevertheless clearly impair serial recall appreciably, indicating that the inhibition is either ineffectual or too weak to bring interference-by-process fully under control. This stands in contrast to the abolition of the deviation effect as a by-product of increased task-engagement seen in the present study. One possibility is that the direct-inhibition type of control witnessed in Hughes and Jones (2003a; see also Marsh, Beaman, Hughes, & Jones, 2012) and in negative priming studies generally constitutes an attempt to reduce distraction in cases where the extraneous material has already intruded ineluctably into response-planning stages of processing (see Tipper, Weaver, & Houghton, 1994). If the irrelevant material does not compete specifically for the response-planning processes involved in the focal task (e.g., as with an auditory deviant), its intrusion can be prevented, and more effectively so, through the focal-task engagement mechanism.[4]

Further evidence that different control mechanisms are involved in modulating the focusability/distractibility balance depending on the particular way in which irrelevant input threatens to impinge on performance comes from auditory distraction effects in semantic-based tasks. For example, in free recall of (visually presented) items taken from a single semantic category (e.g., apple, pear, mango . . .), irrelevant speech tokens taken from the same semantic category ("banana, strawberry, orange . . .") are more disruptive than unrelated tokens ("chair, table, desk . . ."; Beaman, 2004; Marsh, Hughes, & Jones, 2008; Neely & LeCompte, 1999). We have argued that this semantic auditory distraction effect is again, in part, a case of interference-by-process: The obligatory processing of the irrelevant-but-semantically related tokens interfere specifically with the semantic-based processes (e.g., spreading semantic activation), supporting retrieval of the to-be-remembered items (Marsh, Hughes, & Jones, 2008, 2009; Marsh et al., 2012; see also Marsh, Vachon, & Jones, 2008, for similar conclusions with regard to phonological-based processes). This component of the distraction results in fewer of the visually presented to-be-remembered items being recalled. As in the serial recall setting (Hughes & Jones, 2003a), recent evidence using a negative priming procedure suggests that this specific competition is subject to a direct-inhibition process: If the to-be-ignored speech tokens are repeated as the visually presented to-be-remembered items on the next trial, free recall is poorer than when there is no such repetition across trials (Marsh et al., 2012). Critical for present purposes is the observation that there is again no correlation between individual differences in the capacity for task-goal maintenance (as measured by OSPAN) and this specific competition component (Beaman, 2004). A second component of the semantic auditory distraction effect, however, seems to reflect the same factor as that which predicts susceptibility to the auditory deviation effect observed in the present study: a failure to maintain task-engagement. This component is made manifest in free recall, not through poorer recall of the to-be-remembered items, but by intrusion into output protocols of the to-be-ignored auditory distractors. Critically, that this component is indeed related to the capacity for task-engagement is shown by the fact that the frequency of intrusions from the sound is predicted by individual differences in OSPAN (Beaman, 2004). A clear implication of our analysis of the current findings for the semantic auditory distraction setting, therefore, is that factors such as high task-difficulty should help prevent intrusions but leave the direct competition component (reflected in poorer recall) unaffected.

Conclusions

The present findings have served to flesh out the character of the different ways in which focusability can be compromised by the deleterious effect of the generally adaptive capacity for distractibility. In particular, an auditory stimulus that deviates from the recent context can impinge on focal task performance by capturing attention from the task. Accordingly, we have shown here that this form of distraction is a negative function of general task-engagement. This capacity is variable, both across individuals, but also within individuals: Factors such as high task-difficulty and timely cues about likely disruption allow those with relatively low

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[4] One observation that seems inconsistent with this particular dual-mechanism—dual control analysis is that some researchers have reported that working memory capacity, which we have associated with focal-task engagement, correlates with negative priming, often seen as an index of direct inhibition (Conway, Tuholski, Shisler, & Engle, 1999). However, the robustness of the link between negative priming and working memory capacity seems questionable with several subsequent studies failing to find evidence of such a link (e.g., Grant & Dagenbach, 2000; Ossmann & Mulligan, 2003).

working memory capacity to behave, in effect, more like those with higher working memory capacity. This aspect of the present results has clear applied as well as theoretical implications: A reduction in working memory capacity—or poorer attentional control—is associated both with the normal aging of the cognitive system (Salthouse & Babcock, 1991) and also some of the cognitive deficits characterizing schizophrenia (Lee & Park, 2005) and dementia of the Alzheimer's type (e.g., McDowd et al., 2011). The fact that there are relatively simple means of facilitating task-engagement, and in turn distraction-control, could form the basis for practical interventions designed to offset the deleterious consequences of such reductions in working memory capacity. However, there also exists a functionally distinct form of auditory distraction: Cognitive performance is also vulnerable to disruption whenever the obligatory processing of sound leads to information (e.g., order cues) that conflicts with the particular processing engaged to perform the focal (e.g., serial recall) task. In this case, whereas direct inhibition of the irrelevant sound may be at play (Hughes & Jones, 2003a; Marsh et al., 2012), such distraction cannot be controlled through increased focal-task engagement.

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Received December 29, 2011
Revision received April 20, 2012
Accepted May 8, 2012 ■