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Auditory Distraction: A Duplex-Mechanism Account

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Abstract

A body of laboratory work is reviewed suggesting that auditory distraction comes in two functionally distinct forms. Interference-by-process is produced when the involuntary processing of the sound competes for a similar process applied deliberately to perform a focal task. In contrast, attentional capture is produced when the sound causes a disengagement of attention away from the prevailing task, regardless of the task processes involved. Particular attention is devoted to reviewing a range of converging evidence from both experimental and individual- and group-differences based research indicating that auditory attentional capture is controllable via greater top-down task-engagement whereas interference-by-process is not.

KEYWORDS : Auditory distraction; Interference-by-process; Attentional capture; Serial recall; Cognitive control

One of the biggest challenges of day-to-day life is staying focused on the subset of incoming sensations relevant to an immediate goal (e.g., the pattern of light produced by the words on this page) whilst ignoring irrelevant information (someone chatting outside in the corridor). However, a key paradox is that this need to remain focused is coupled with a simultaneous need to continue processing the 'irrelevant' information so that our attention can be readily switched to it if our immediate goals change or if there are marked changes in the environment itself that might signal events that need to be acted upon swiftly (e.g., the chatty person in the corridor suddenly shouting 'fire!'). In turn, a cost of this essential openness to task-irrelevant stimuli is *unwanted* distraction: Focal mental processing is at the mercy of disruption by stimuli that do not necessarily require a response. Both the openness of the cognitive system and the concomitant potential cost of unwanted distraction is particularly apparent in relation to auditory stimuli because our ears cannot be easily shut or averted to avoid registering sound (unlike the eyes in relation to light) and we register sound even in darkness and from all directions (again, unlike the case for vision). The goal of the present paper is to review evidence derived mainly from laboratory studies of the disruption by sound of simple short-term memory tasks for a duplex-mechanism account of auditory distraction: Sound can cause unwanted distraction either by interfering specifically with the processes involved in the focal task (*interference-by-process*) or by diverting attention away from a focal task regardless of the type of processing that task involves (*attentional capture*). Interest will centre in particular on reviewing recently emerging evidence suggesting that whereas attentional capture can be controlled through greater engagement in focal task-processing, the other cannot.

Auditory Distraction Type I: Interference-by-Process

It has long been argued that one mechanism by which task-irrelevant sound disrupts cognitive task performance is by interfering with the particular processes involved in the given focal task (e.g., Jones & Macken, 1993). The action of this distraction mechanism has been demonstrated mainly in the context of short-term serial recall in which, typically, participants are asked to recall in order a list of around six to eight verbal items (e.g., digits, letters) presented one by one on a screen at the rate of approximately one or two items per second. Serial recall is impaired appreciably by the mere presence of sound, whether that sound is presented during the presentation of the to-be-remembered items or during a short retention interval between the last to-be-remembered item and a recall cue (Colle & Welsh, 1976; Ellermeier & Zimmer, 1997; Elliott, 2002; Neath, 2000; Röer, Bell, Dentale, & Buchner, 2011; Salamé & Baddeley, 1982; Jones, Madden, & Miles, 1990). This is the case despite the fact participants are explicitly told to ignore the sound and that they will never be tested on its contents. A key signature of the disruption as far as the sound is concerned is that, for marked and consistently reliable disruption, it must be changing acoustically from one perceptually segmentable entity to the next. Thus, a sequence such as *"B, Q, J, G..." or "B, Q, B, Q…",* or a succession of tones in which each differs in frequency from the last, produces marked disruption whereas a steady-state item (*"B, B, B, B...";* or a repeating tone) produces little if any disruption compared to quiet (e.g., Divin, Coyle, & James, 2001; Hughes, Tremblay, & Jones, 2005; Jones & Macken, 1993). In contrast, other, non-acoustic, properties of sound such as phonology or meaning (when speech is used) play a relatively minor, if any, role in the disruption of serial recall (e.g., Buchner, Irmen, & Erdfelder, 1996; Jones & Macken, 1995a; Jones et al., 1990; Marsh, Hughes, & Jones, 2008).

A large body of work suggests that this *changing-state effect* is an example of auditory distraction caused by interference-by-process: the distraction is a joint product of processes being applied in an involuntary fashion to the sound and the nature of the focal serial short-term memory task (e.g., Jones & Macken, 1993; Jones et al., 1999; Macken et al., 2009). Specifically, it is assumed that the changes from one successive sound element to the next give rise to cues pertaining to the order of the sounds. This extraneous order information interferes specifically with the deliberate, goal-driven, process of rehearsing the to-be-remembered items in serial order in support of their eventual sequential output (see, e.g., Jones & Macken, 1993; this volume).

Whilst the changing-state effect in serial recall will be used as the key example of distraction through interference-by-process in this review, it is important to note that this form of distraction can be witnessed also in other task-settings. Most notably, an interference-by-process analysis has been applied to auditory distraction in the context of several settings in which focal semantic processing is a dominant feature, in contrast to the articulatory-based serial processing that dominates serial recall of relatively meaningless items such as digits or letters (e.g., Jones, Marsh, & Hughes, 2012; Marsh, Hughes, & Jones, 2008, 2009; Marsh, Beaman, Hughes, & Jones, 2012). For instance, if the task involves the free recall of a list of words from a single semantic category (e.g., *apple, pear, strawberry…*), it is now the semantic rather than acoustic features of task-irrelevant speech that assume disruptive potency. Thus, irrelevant speech that is semantically related to the to-be-remembered words (e.g., *orange, peach, banana…*)—compared to unrelated speech (e.g., *eagle, sparrow…*)—is particularly disruptive in this task-setting (Marsh et al., 2008). Similarly, in a semantic fluency task in which participants are asked to generate as many words as they can from a given semantic category (e.g., fruit), irrelevant spoken words drawn from a semantically-related category (vegetables) are more disruptive to performance than words drawn from an unrelated category (e.g., furniture; Jones et al., 2012). Within the interference-by-process approach, such semantic distraction effects can be explained by supposing that semantically similar speech causes automatic spreading of activation through a long-term semantic network which interferes with the similar process of navigating such networks for the purpose of retrieval in the focal task (for further discussion, see Marsh & Jones, 2010).

Auditory Distraction Type II: Attentional Capture

The second mechanism of auditory distraction within the duplex-mechanism account is *attentional capture* whereby attention is at least momentarily disengaged from the focal task, regardless of the particular processing involved in that task (e.g., Escera, Alho, Winkler, & Näätänen, 1998; Hughes, Vachon, & Jones, 2005; Lange, 2005; Parmentier, Elford, Escera, Andrés, & San Miguel, 2008; Sörqvist, 2010; Vachon, Hughes, & Jones, 2012). Attentional capture can, in turn, be divided into two classes (Eimer, Nattkemper, Schröger, & Prinz, 1996): *Specific* attentional capture occurs when it is the particular content of the sound that endows it with attention-diverting power such as when one hears their own name being called (e.g., Conway, Cowan, & Bunting, 2001; Moray, 1959; Röer, Bell, & Buchner, 2013; Wood & Cowan, 1995) or sound that is otherwise meaningful or of interest to a given individual (e.g., a mother hearing her own baby's cries; the sound of cooking for a hungry person). *Aspecific* attentional capture is produced when there is nothing inherent in the event itself that is attention-capturing; rather, it captures attention because of the context in which it occurs. Thus, if a sound (*A*) of a particular frequency (Hz) is presented following a succession of sounds of a different frequency—*BBBBB**A**BB*—*A* will tend to capture attention because it violates the expectation for another *B*. But this has nothing to do with the properties of *A* per se; *B* would tend to capture attention in the sequence *AAAAA**B**AA* (e.g., Escera, Alho, Winkler, & Näätänen, 1998; Hughes et al., 2005; Hughes, Vachon, & Jones; 2007; Näätänen, 1990; Parmentier, 2008; Schröger & Wolff, 1998). That an auditory deviation captures attention is indicated by the fact that when presented as part of a task-irrelevant sequence of sounds, it disrupts performance of a range of focal cognitive tasks (e.g., Hughes et al., 2007; Parmentier et al., 2008; Schröger & Wolff, 1998; see also next sub-section).

Of particular relevance for present purposes is that auditory deviations disrupt serial recall performance. For example, if, on a relatively small number of trials, a word spoken in a male voice is embedded in a task-irrelevant sequence of female-spoken words (or vice versa), serial recall is impaired appreciably (Hughes et al., 2007, 2013). On the grounds of parsimony alone, it would be tempting to assume that this deviation effect and the changing-state effect on serial recall performance are instances of the same phenomenon. However, the distinction at the heart of the duplex-mechanism account—that between interference-by-process and attentional capture—has, in part, been based on various functional dissociations between the impact of an auditory deviation and the changing-state effect. The first of these to be considered here relates to the different role played by the qualitative nature of the focal task in the two forms of auditory distraction.

Differential Task-Sensitivity

The interference-by-process view of the changing-state effect posits that changing- compared to steady-state sound specifically disrupts serial rehearsal, that is, this form of distraction is task-process sensitive. Evidence for this form of distraction within the serial recall setting comes from the finding that if the involvement of serial rehearsal is reduced by asking participants to engage in articulatory suppression (repeated articulation of an irrelevant verbal sequence during the task), the changing-state effect disappears (Jones, Macken, & Nicholls, 2004; see also Hanley, 1997; Salamé & Baddeley, 1982). Furthermore, if the locus of the sound-sequence is manipulated such that it accompanies a point in the serial recall task in which the demand on rehearsal processes is relatively low (e.g., as the first few to-be-remembered items are presented), changing-state sound is less disruptive than if it accompanies a point in which rehearsal demand is relatively high (e.g., late during list presentation; Macken, Mosdell, & Jones, 1999). Another line of evidence for the task-process sensitivity of the changing-state effect comes from studies that have examined whether changing-state sound is also disruptive of tasks that are assumed not to invoke a serial rehearsal strategy (Beaman & Jones, 1997; Hughes et al., 2007; Jones & Macken, 1993). Take, for example, the missing-item task which shares most of its characteristics with serial recall—the nature of the to-be-remembered items, their rate of presentation, and list length—but the list is made up of a set from which one member is missing (e.g., eight of the nine digits from the set *1-9* presented in random order). Rather than recall the items in order (serial recall), the task here is to report the missing item (e.g., Buschke, 1963). This short-term memory task does not require the order of the items to be retained and serial rehearsal does not seem to be adopted as a strategy to perform the task (as evidenced by the fact that it is relatively immune to the impact of articulatory suppression; Klapp, Marshburn, & Lester, 1983). In line with the interference-by-process account, the missing-item task is not disrupted by changing- compared to steady-state sound (e.g., Hughes et al., 2007; Jones & Macken, 1993).

In contrast, attentional capture does not appear to be task-process sensitive so long as the task is attention-demanding (i.e., the task must not be automatized to the extent that it is immune to any form of interference; cf. Neumann, 1987). Certainly, serial rehearsal is not peculiarly vulnerable to attentional capture as appears to be the case with the changing-state effect. For example, specific attentional capture by one’s own name is found in a task involving the shadowing of a speech sequence which is unlikely to place a heavy burden on serial rehearsal (Wood & Cowan, 1995). Aspecific attentional capture by an auditory deviation has also been reported in the context of a wide range of focal tasks including the speeded classification of visually presented digits (as odd or even; Parmentier et al., 2008) or of the duration of each of a succession of tones (e.g., Schröger & Wolff, 1998). Perhaps the most direct evidence for a distinction between interference-by-process and attentional capture in terms of differential task-sensitivity, however, comes from the finding that whilst the missing-item task is immune to a changing-state effect, it is indeed disrupted appreciably by a deviant (Hughes et al., 2007). This dissociation also helps to counter the possible objection that missing-item performance may not be susceptible to a changing-state effect because such performance is insensitive to *any* form of disruption by task-irrelevant sounds.

It should be noted that whilst the duplex-mechanism account posits that there are fundamental differences between the changing-state effect and aspecific attentional capture, they may both ultimately be the result of sequential auditory streaming. This is the process whereby the auditory system integrates successive sounds that have derived from the same environmental source into the same temporally-extended perceptual object (or ‘stream’) or, alternatively, partitions successive events from different sources into separate streams. In the case of the changing-state effect, there is evidence that it is the integration of stimuli that are changing but that are nevertheless similar enough to be integrated into a single stream that yields order cues that then interfere with serial recall (e.g., different words but all spoken in the same voice; see Jones & Macken, 1995a; Jones, Alford, Bridges, Tremblay, & Macken, 1999). In contrast, registering an event as a deviation may correspond to the perception of a change that is sufficiently large to be perceived as the onset of a new environmental event and hence one that warrants an interruption of focal processing so that its possible significance can be evaluated (e.g., Sussman et al., 2007). Whilst Macken & Jones (this volume) discuss this shared antecedent of the changing-state effect and the deviation effect in some detail, the current review focuses on evidence suggesting that there is a fundamental difference in the manner in which they disrupt task-performance.

Differential Cognitive Control

There has been a great deal of interest in recent years in the extent to which distraction (both visual and auditory) is not merely a function of the properties of the distracting material itself (‘bottom-up’ factors) but also factors internal to the individual (‘top-down’ factors; e.g., Monsell & Driver, 2001). For example, it has been argued that one way in which top-down cognitive control may be exercised is through the boosted activation of representations pertaining to the focal task including a preparatory task-set, the panoply of representations preactivated in preparation for optimal performance of any goal-driven task such as the task-goal, rules and strategies for meeting that goal, and probable upcoming stimuli (e.g., Desimone & Duncan, 1995; Engle, 2002; MacLeod et al., 2003). Of particular interest here is the commonly held view that there exists not only inter-person variation in the overall capacity for cognitive control through increased task-engagement (e.g., Engle, 2002) but also intra-individual variation over time which can be influenced by a range of factors including task-demands, emotional state, and motivational factors (Matthews et al., 2002). Evidence from various task-settings suggests that whilst interference-by-process cannot be brought under cognitive control via an increased task-engagement, (some) individuals are indeed able to exert such cognitive control over distraction due to auditory attentional capture. This evidence comes from experimental findings pertaining to the influence of various forms of task-demand, the effects of foreknowledge of potential distraction, and individual differences in susceptibility to auditory distraction both within adults and across different developmental populations.

The Influence of Task-Demand

One line of experimental evidence that greater task-engagement shields against auditory attentional capture but not interference-by-process is that promoting greater task-engagement by making the focal task more demanding reduces or eliminates the disruptive impact of a deviant sound but not the changing-state effect. For example, in Hughes et al. (2013), the difficulty of a serial recall task was increased by embedding the to-be-remembered items in static visual noise. Separate studies had established that it takes longer to identify stimuli degraded in this way but that accuracy remains high (Hughes et al., 2013;

Parmentier et al., 2008). It was found that whilst high encoding-difficulty did not directly affect serial recall performance, it eliminated the marked disruption of serial recall by an auditory deviant. It did not, however, influence the changing-state effect: interference-by-process seems to be immune to the same perceptual degradation manipulation that attenuates attentional capture. This can be explained by supposing that high encoding-difficulty does not necessarily affect the extent to which the to-be-remembered items—so long as they can be encoded accurately—are rehearsed; hence, the key precondition for the changing-state effect as far as focal-task processing is concerned remains. Indeed, the fact that high encoding-difficulty did not impair serial recall directly is consistent with the notion that rehearsal was not affected to any appreciable extent.

The distraction-shielding effect of increased visual encoding-difficulty extends to a variety of manipulations of encoding-difficulty, to different cognitive tasks, and to properties of sound other than deviations: For example, proof-reading a text presented in a difficult-to-encode font (Haettenschweil) is appreciably less susceptible to distraction from irrelevant meaningful speech (compared to quiet) than proof-reading the same text presented in a relatively easy-to-encode font (Times New Roman; Halin, Marsh, Haga, Holmgren, & Sörqvist, 2013). A comparable effect is observed when memory for the text is tested (Halin, Marsh, & Sörqvist, personal communication). Finally, Marsh, Sörqvist, and Hughes (2013) have shown that irrelevant spoken words semantically related to a list of words presented for free recall is less likely to disrupt recall and intrudes less into participants' responses if the words are presented in static visual noise (cf. Hughes et al., 2013). One theoretical implication of this work from the standpoint of the duplex-mechanism account is that at least some of the disruptive effect of semantically similar speech on semantic-based cognitive tasks (e.g., Bell, Buchner, & Mund, 2008; Marsh et al., 2008) may be due to (a specific form of) attentional capture (cf. Eimer et al., 1996).

On the face of it, it might be argued that rather than eliciting a top-down cognitive response (increased task-engagement), high encoding-difficulty may instead be a passive, bottom-up, consequence of high 'perceptual load' (Lavie, 1995, 2005; Lavie & Tsal, 1994). In many studies of visual attention, Lavie and colleagues have shown that making perceptual identification of a visual target more demanding by, for example, embedding it amongst other, non-target, stimuli, distraction from visual distractors presented outside the target-area is attenuated. This has been explained by supposing that "perception has limited capacity…. but processes all stimuli in an automatic fashion… until it runs out of capacity… [so that] high perceptual load that engages full capacity in relevant processing would leave no spare capacity for perception of task-irrelevant stimuli" (Lavie, 2005, p. 75). Within this perceptual-load based account, then, the effect of high encoding-difficulty on auditory attentional capture in serial recall could be (re)interpreted as a passive by-product of the depletion of an attentional resource dedicated to perceptual processing, not a top-down cognitive response to increased task-demands.

There are several lines of converging evidence that support the top-down control account over the perceptual-load based account of the reduction of auditory attentional capture due to perceptual degradation. First, according to Lavie's Load Theory—of which the perceptual load model is one part—sensory degradation of task-relevant stimuli does not in fact constitute an increase in perceptual load but rather sensory load (Lavie and De Fockert, 2003). Given that, according to Load Theory, high sensory load increases rather than reduces distraction (Lavie and De Fockert, 2003), this alternative conceptualization of what we have called high encoding-difficulty runs into difficulties. Even if the definition of perceptual load was extended to include manipulations involving sensory degradation, the fact that it reduces the deviation effect but not the changing-state effect supports the top-down view: If the processing of a sound-sequence is filtered out early because perceptual degradation depletes a limited perceptual resource, then it seems reasonable to expect that any form of distraction produced by that sound-sequence should be attenuated. However, as noted, disruption of serial recall due to interference-by-process (i.e., changing-state effect) is not affected by perceptual degradation of the to-be-remembered items (Hughes et al., 2013).

Yet further evidence against a perceptual load-based account of the effect of perceptual degradation comes from recent evidence that an increase in task-demand that does not involve altering bottom-up factors (unlike the perceptual degradation method) seems to exert the same influence on the deviation effect as high encoding-difficulty. For example, requiring participants to undertake a secondary cognitive load in the form of (whispered) concurrent articulation also eliminates the deviation effect (Hughes, Hurlstone, & Jones, 2014). One possible explanation for this is that, like the changing-state effect, verbal rehearsal is particularly susceptible to the deviation effect and so concurrent articulation serves to strip the task of that aspect (verbal rehearsal) that renders it vulnerable (cf. Jones et al., 2004). However, the fact that the deviation effect is of comparable magnitude in tasks devoid of serial rehearsal (Hughes et al., 2007) suggests against this interpretation. Another possible explanation, therefore, is that rather than exerting its effect by blocking rehearsal, concurrent articulation in this case—as with high encoding-difficulty within the focal task (Hughes et al., 2013)—serves to increase the overall demand on processing that is unrelated to the sound and hence again shields against capture by a deviant within that sound.

In seeking to adjudicate directly between these two accounts, Hughes et al. (2014) reasoned that if verbal rehearsal underpins the deviation effect, then increasing the load on rehearsal should exacerbate that effect just as it does the changing-state effect. If, however, any processing demand unrelated to the sound attenuates attentional capture by a deviant, then such capture should be reduced under increased rehearsal demand. Following Macken et al. (1999), the locus of the irrelevant sound-sequence was varied such as to accompany the first few items in the list, the last few items, or during a retention interval between the last item and a recall cue. The key assumption is that the demand on rehearsal is relatively low early during list presentation but becomes heavier towards the end of the list and during a retention interval. Replicating Macken et al. (1999), the changing-state effect was accentuated under increased rehearsal demand. However, whereas a deviant disrupted performance when presented relatively early in list processing, its deleterious impact was *reduced* when presented late in the list or early during a retention interval (Hughes et al., 2014). Thus, this not only provides a futher dissocation between the changing-state and deviation effects, it supports the view that any increase in goal-driven processing that is unrelated to the sound —whether 'perceptual' or 'cognitive'—shields against attentional capture by sound. The pattern of results also suggests that the observation that a deviation effect is found during presentation but not during a retention interval does not necessarily imply that stimulus-encoding is peculiarly susceptible to this effect as first suggested (cf. Hughes et al., 2005); rather, it appears to be because task-engagement is greater during the retention interval (though see Röer, Bell, & Buchner, 2013).

A broader implication of the apparent equivalence of increased perceptual and cognitive demands on attentional capture by an auditory deviant is that it challenges a fundamental distinction often made between these two types of mental demand. For example, according to Lavie (2005, p. 80), "load on executive control functions, such as working memory, that renders them unavailable to actively maintain stimulus-processing priorities throughout task performance has the opposite effect to perceptual load: it increases interference by irrelevant low-priority distractors rather than decreases it." (Lavie 2005 p. 80). And indeed, there is a good deal of support for this distinction in uni-visual distraction settings (e.g., De Fockert, Rees, Frith, & Lavie, 2001; Lavie et al., 2004). However, assuming that engaging in a secondary activity (e.g., concurrent articulation) and increased demand on rehearsal can be regarded as imposing higher demands on working memory (or ‘cognitive control’; see Lavie, 2005), the fact that these variables exert the same impact on the deviation effect as high encoding-difficulty (vis-à-vis ‘perceptual load’) seems to cast serious doubt upon the applicability of the distinction between perceptual and cognitive load to auditory distraction.

Indeed, there are numerous other instances outside of the serial recall setting in which a supposed increase in cognitive load reduces rather than increases auditory distraction. For example, reaction time (RT) to discriminate the duration of each of a series of tones (long vs. short) is impaired to a lesser degree by a rare deviation in the frequency of a tone (*n*) when cognitive load is increased by requiring discrimination of the duration of tone $n - 1$ rather than tone *n*. (i.e., an ‘*n*-back’ task; Berti and Schröger, 2003). The same result is obtained when the to-be-classified stimulus is a visually presented stimulus that follows each sound [where the increase in WM load is again implemented using a one-back condition (SanMiguel, Corral, & Escera, 2008; SanMiguel, Linden, & Escera, 2010) or by increasing the number of response-alternatives (Parmentier et al., 2008)]. There are also event-related potential data suggesting that greater active-engagement shields against deviation effects: For example, Harmony et al. (2000) asked participants to re-order a series of five visually-presented letters (e.g., ABTEL) into a word (TABLE) or to simply report the identity of a single repeated letter (e.g., AAAAA). In the latter condition, the authors found a P3a wave—widely regarded as a neural marker of auditory attentional capture in response to the presence of a frequency-deviant tone. However, in the former condition the P3a was attenuated. Similarly, Muller-Gass, Stelmack, and Campbell (2006) found that the P3a elicited by a rare deviation in the intensity of background sounds was attenuated when the discriminability of task-relevant visual target stimuli was reduced and Zhang, Chen, Yuan, Zhang, and He (2006) also reported that the P3a response to an auditory deviant was attenuated when the number of moving visual objects to be tracked was increased from one to three. Thus, further research is clearly required to determine why high cognitive load increases distraction in certain uni-visual settings (Lavie, 2005) but reduces auditory deviation effects (though see Benoni & Tsal, 2013, for doubts regarding the validity of the distinction even in the context of visual distraction).

The Role of Expectations

Further evidence that attentional capture (but not interference-by-process) is amenable to top-down cognitive control comes from the impact of providing a warning about potential distraction. For instance, Sussman, Winkler, and Schröger (2003) asked participants to judge the duration (short or long) of each of a succession of tones as quickly and as accurately as possible. A deviation in the frequency (Hz) of a tone captured attention as indexed by a delay in the response to its duration. This deviation effect was eliminated, however, if a visual warning was given about the imminent deviation (see also Horváth, Sussman, Winkler, & Schröger, 2011). A warning about potential distraction can also aid the resumption of a task following attentional capture by an auditory deviation: Shelton, Elliott, Eaves, and Exner (2009) found that performance of a visually presented lexical-decision task recovered more quickly from disruption by a mobile phone-ring presented against an otherwise quiet background if participants were warned that a phone-ring would be presented at some point during the task. The impact of an auditory deviant in the context of serial recall is also eliminated if, just before the critical trial, participants are told that an auditory deviation will occur (Hughes et al., 2013). Such effects of forewarning seem, like high encoding-difficulty, to be most readily explained in terms of greater task-engagement; presumably, the expectation for a potentially capturing sound is incorporated into the task-set in order to shield ongoing performance from intrusion by the deviation (see also Vachon et al., 2012).

In contrast to attentional capture, interference-by-process—at least as indexed by the changing-state effect on serial recall—is not modulated by top-down knowledge about the sound. For example, a changing-state sequence continues to disrupt serial recall appreciably even when participants encounter the same two alternating spoken words nearly 2000 times across many trials (Röer et al., 2011). Furthermore, when an explicit cue is provided that a changing-state as opposed to steady-state sequence is about to be presented, the disruptive impact of the former compared to the latter is unaltered (Hughes et al., 2013).

Evidence From Individual Differences in Distractibility

There is convergent psychometric evidence for the view that attentional capture by sound but not interference-by-process is amenable to top-down cognitive control. For example, it is well accepted that there are stable individual differences in "working memory capacity" (WMC) as measured by performance on complex span tasks such as reading span (Daneman & Carpenter, 1980) and (arithmetic) operation span (Turner & Engle, 1989). Critical for present purposes is the commonly-made supposition that WMC is largely if not wholly equivalent to the capacity to exert top-down cognitive control, particularly in the face of potentially distracting influences (Kane, Bleckley, Conway, & Engle, 2001; Engle & Kane, 2004). In line with this view, individuals high in WMC are typically found to be less susceptible to distraction from task-irrelevant stimuli. For example, high-WMC individuals are less likely to be distracted by their own name presented to the to-be-ignored ear while shadowing prose presented to the other (Conway et al., 2001), less susceptible to distraction in the classic Stroop task (Kane & Engle, 2003), and less prone to false recall of semantically-related distracters in the context of auditory semantic distraction settings (e.g., Beaman, 2004). Such results are clearly consistent with the notion that individuals with high WMC are "better able to inhibit or suppress irrelevant information and to prevent it entering working memory" (Engle, 1996, p. 111). Of most relevance to the present argument, high

WMC individuals are less susceptible to the deviation effect (Hughes et al., 2013; Sörqvist, 2010; Sörqvist et al., in press) but not to the changing-state effect (Beaman, 2004; Hughes et al., 2013; Elliott & Briganti, 2012; Elliott & Cowan, 2005; Sörqvist, 2010; Sörqvist, Marsh, & Nöstl, in press; see also Ellermeier & Zimmer, 1997; Macken, Phelps, & Jones, 2009; Neath, Farley, & Surprenant, 2003).

An interesting parallel between the duplex-mechanism account of auditory distraction and the study of individual differences in WMC is the duality of the disruption found in the classic Stroop task in which participants must name the colour in which a colour-word (e.g., ‘red’ written in blue) is printed (see MacLeod, 1991): It has been shown that low-WMC individuals are only more susceptible to the general goal-maintenance component of Stroop interference (to remember to name the color rather than read the word), a component indexed by the inadvertent reporting of the word (i.e., an intrusion error) or slower RTs on incongruent trials but only at the tail of the RT distribution (i.e., an increase in the number of very slow responses). There are not, in contrast, WMC-related individual differences in the task-process specific component of Stroop distraction, namely, that related to competition-resolution (i.e., Stroop interference ‘proper’; e.g., Morey et al., 2012; Unsworth, Redick, Spillers, & Brewer, 2012; see also Keye, Wilhelm, Oberauer, & van Ravenzwaaij, 2009; Redick, Calvo, Gay, & Engle, 2011). Here again, then, general task-engagement appears to be under top-down cognitive control but not the influence of stimuli (or stimulus dimensions) that are incongruent with the particular demands of the focal task.

Developmental Differences in Distractibility

A further strand of support for the duplex-mechanism account is emerging from developmental studies of auditory distraction. It is well established that children (e.g., aged 8 years) show more disruption by irrelevant speech of serial recall than young adults (Elliott, 2002; Elliott & Briganti, 2012). Recent evidence suggests that this increased susceptibility may be specifically attributable to increased susceptibility to attentional capture, not interference-by-process (Elliott, Hughes, Briganti, & Macken, 2013; see also Klatte, Lachmann, Schlittmeier, & Hellbruck, 2010). Elliott et al. (2013) examined children and adults' performance of two tasks in the presence of irrelevant speech. One task—the probed order task—was similar to serial recall except that at test one of the to-be-remembered items was (re)presented and the task was to recall which item followed it in the list (e.g., Murdock, 1968). Thus, performance of this task, like serial recall, should show a changing-state effect. The second task was the missing-item task described earlier which is devoid of the need for serial rehearsal and, accordingly, is immune to the changing-state effect (e.g., Hughes et al., 2007; Jones & Macken, 1993). The results showed the expected pattern for adults: They exhibited a changing-state effect in the probe task but not in the missing-item task. However, the novel aspect of the results was the distinct pattern found in the children: Whilst they showed a changing-state effect in the probe task and none in the missing-item task (as with adults), the largest distraction effect for children was found in the contrast between steady-state sound compared to quiet and this relatively large effect of the mere presence of sound (i.e., regardless of whether it was changing or not) was found on both the probe and missing-item task. Thus, the greater susceptibility of children to auditory distraction appears to be attributable to their greater tendency to disengage from the focal task in the presence of *any* sound and regardless of the qualitative nature of the focal task.

Also consistent with an attentional capture account of the increased susceptibility of children compared to adults is that the former have a relatively low WMC (and hence lower attentional control; Cowan et al., 2005). Thus, their distractibility may be analagous functionally to that of adults with very low WMC. However, apparently at odds with this hypothesis is that individual differences in WMC *within* child-participant samples does not correlate with their distractibility (e.g., Elliott & Briganti, 2012). One possible explanation for this is that the measures taken of distractibility have not isolated the proportion of disruption attributable to attentional capture (which should correlate with WMC) and that attributable to the changing-state effect (for which there are individual differences but ones that do not correlate with WMC; see Macken et al., 2009). Thus, it is possible that individual differences in the changing-state effect obscure an actual relationship between WMC and individual differences in distraction produced by attentional capture. It would seem worthwhile, therefore, to try to partition the variability accounted for by the two forms of distraction in future individual-differences based studies of auditory distraction.

Summary and Conclusions

In this paper, evidence has been reviewed suggesting that distraction of cognitive performance by sound takes two functionally distinct forms. Interference-by-process—illustrated here through the changing-state effect in serial recall—occurs when the processing of the sound competes specifically for the control of a particular process (serial rehearsal) involved in the focal task. Accordingly, whilst greater engagement in serial rehearsal increases this form of distraction, greater engagement in task-processing unrelated to serial rehearsal (due to high encoding-difficulty or preparing for distraction in light of foreknowledge of potential distraction) has no effect. Individual differences in the capacity to prioritize task-relevant over task-irrelevant processing are also unrelated to interference-by-process. In contrast, auditory attentional capture occurs whenever the sound causes a disengagement away from the focal task, regardless of the qualitative nature of that task. Whilst many types of sound may potentially cause specific attentional capture, interest has centred here on aspecific attentional capture caused by a deviation from the prevailing sound-sequence. A body of work from a variety of task-settings suggests that attentional capture can indeed be resisted via greater engagement in processing unrelated to the sound, at least by those individuals deemed to be high in working memory capacity. In light of such evidence for a distinction between two forms of auditory distraction—one controllable by the individual, the other less so, if at all—it is important in future research that efforts are made to systematically isolate their possible individual contributions to the overall disruption of task performance.

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