Varieties of auditory distraction

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INTRODUCTION

Historically, laboratory research on the effects of noise on performance is split into two eras; one, up to the 1970s was concerned with how loud white noise interfered with cognitive and motor tasks (see Jones & Broadbent 1991, for an overview), the other, from the 1980s recognized that sound need not be loud to be distracting, indeed, speech sounds as quiet as a whisper could disrupt cognitive performance appreciably. This was something that we all knew from personal experience, but it had been difficult to demonstrate it in the laboratory. In the thirty years or so since this second era of research was begun, the scope of mental activities found to be susceptible to distraction from not-very-loud sounds has broadened appreciably and at the same time our understanding of these effects has increased steadily. This paper attempts to chart this progress and set out the areas of residual ignorance in an attempt to guide further work.

REVIEW

Studies of the threshold at which noise has behavioral effects have all but disappeared – those studies that we shall be describing use sounds roughly in the range 50 to 75 dB(A) – rather, the preoccupation is now with how the content of the sound together with the nature of the mental activity, or focal task, results in distraction. At the same time, this implies that when considering contexts outside the laboratory, a preoccupation with sound intensity will be misleading; instead, understanding the nature of mental work and its relationship to the nature of the sound will help us understand the likely level of distraction. The resulting 'big picture' is rather complex and involved, to the extent that research is converging on the conclusion that there are several distinct varieties of distraction and that even within a variety there are subtle distinctions, ones that are perhaps a little arcane but which are nevertheless important to our understanding of distraction. For some readers it will be enough to know what types of mental activity and what types of sound should be avoided if one wants to preserve efficiency in noisy settings, but we hope that there will be others who might be interested in the detail of just how low-intensity sound disrupts cognitive performance.

Much of the action of irrelevant sound on cognition seems to stem from the sentinel character of the auditory modality. We argue that sound is subject to obligatory processing, so that organisational processes such as streaming, occur without conscious attention or effort. In essence, we think these organisational processes impair the performance of concurrent cognitive tasks. Hearing's capacity to inform about remote, novel, possibly important, events bestows upon it a unique position among the senses, contributing to the balancing act required of the brain's attentional system: the need to focus on and engage steadfastly with the task at hand while at the same time remaining open to changes in the environment that might have important consequences for adaptation.

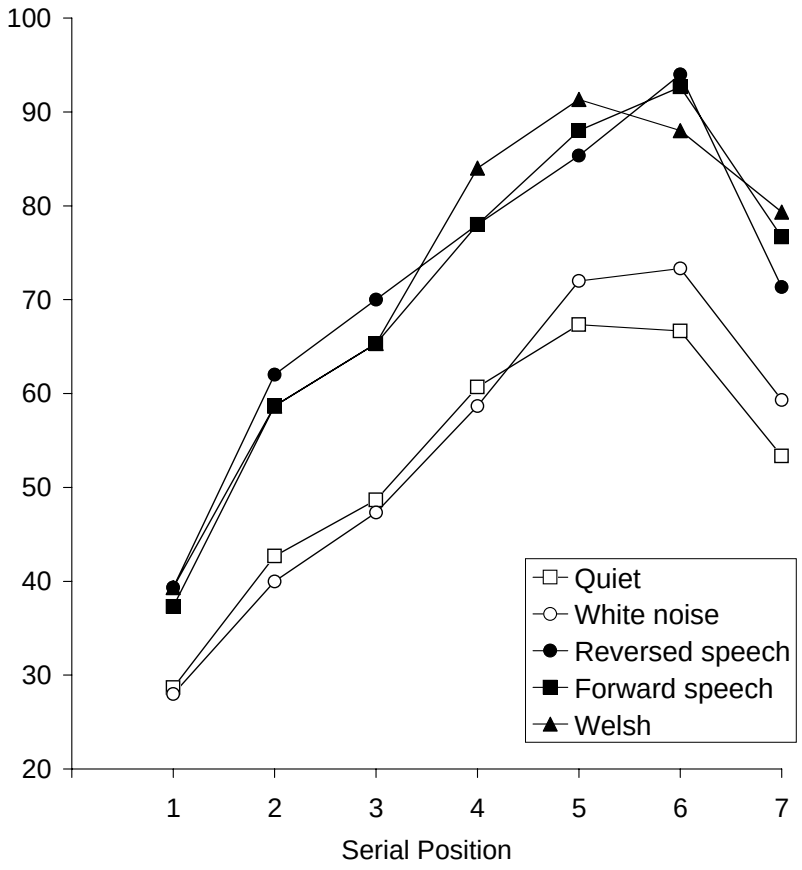

Figure 1: Serial recall performance under conditions of white noise, narrative English, narrative Welsh (the participants were monoglot English speakers), reversed narrative English, as compared to a quiet condition. Errors are shown in relation to presentation position of the seven-item to-be-remembered sequences (Redrawn from Jones et al. 1990).

Memory, in particular, has turned out to be exquisitely sensitive to disruption by background or irrelevant sound: the degree of disruption is both stable and appreciable (typically around 30 %), but they key importance of this result is more because of memory's pivotal role in underpinning a host of behaviors as much as it has to do with the size of the effect (see Ellermeier & Zimmer 1997, for the psychometric characteristics of the effect). For example, short-term memory plays a key role in a range of language skills, its role being particularly prominent when the person is unskilled, or under stress. So, whilst we acknowledge that laboratory research typically uses simple tasks, they are ones that are, nevertheless, often a key component of complex skills such as may be deployed in a wide range of circumstances outside the laboratory.

The Vulnerability of Memory for Order

One of the earliest demonstrations of the vulnerability of cognition to irrelevant sound was conducted by Colle & Welsh (1976). Participants were asked to remember a sequence of visually-presented letter-names and recall them in the right order. Typically, individuals find this difficult; if the list is longer than about four items, errors are almost inevitable, particularly to the memory for order of items in the middle of the list. On some trials, irrelevant sound in the form of a narrative passage – which participants were told was irrelevant and were asked to ignore – was played at a modest level. Figure 1 shows a typical result from this setting. The loss of order memory from irrelevant speech is appreciable, but notice that the effect is absent if the irrelevant sound is white noise, and also that the magnitude of the effect is unchanged if the

irrelevant sound is either played backwards or is in a language that the participant does not understand.

Clearly, the meaning of the sound seems unimportant, but speech seems to be an important pre-requisite, possibly because the focal memory task used verbal stimuli. But both these conclusions, to different degrees, turned out to be wrong.

First, speech turns out not to be a necessary condition. Later work was able to show that pure tones produced disruption – to a diminished degree, granted, as did band-pass noise (providing it conveyed center-frequency changes) – but appreciable disruption nevertheless. Instead another qualification became apparent, both for sequences of speech sounds and for tones, the condition necessary for disruption was that there was acoustic variability, that is, the sound had to change: repeated sequences of tones or speech produced no effects, but when they varied in composition the sound was disruptive. This result was important for a variety of reasons, not least that it ruled out certain classes of explanation. Among these was the idea that the irrelevant speech sound was arriving at some point in the brain at which the phonological or speech-like character of materials was being processed and that the disruption was based on the degree of similarity between the to-be-remembered visual items and the to-be-ignored sound. Later results ruled out such an explanation, but left the question of just how the disruption occurred unanswered.

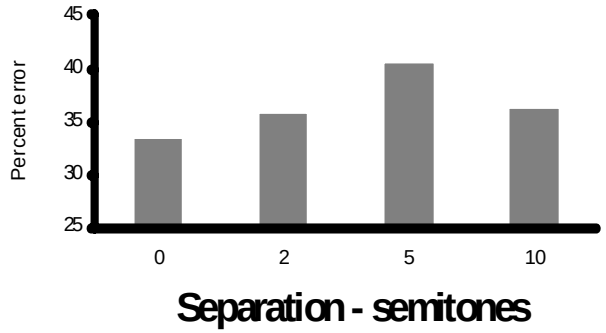

Figure 2: Effect of frequency separation of tones in an irrelevant sequence on serial recall

Two types of evidence, one relating to the nature of the focal task, the other relating to the organisation of the irrelevant sound, were instrumental in furnishing a plausible hypothesis. A number of studies suggested that the organisation of the irrelevant sound played a pivotal role. Figure 2 shows the effect of the auditory organisation of sound as ABA triplets are played in which the pitch difference between the A and the B components is increased (see Jones et al. 1999). Performance is hardly affected when the difference is small and increases appreciably as the pitch difference increases, but this diminishes again when the pitch is very large. Another way of seeing this manipulation of pitch is in terms of degree of change in the sequence; disruption is minimized when the degree of change is small (either when there is one unchanging stream or when the pitch difference results in fission of the sequence into two unchanging streams). This ‘changing state’ condition seems to be an important and general effect: It is true for all types of auditory stimuli – speech and non-speech – in this setting. We shall return to the significance of this finding shortly.

Second, that the focal memory task is verbal is neither a sufficient nor necessary condition for disruption. If we alter the focal task so that it does not require memory for order, but nevertheless involves verbal material, then the distracting effect is

markedly reduced if present at all. So, a sequence of six days of the week, drawn without replacement from the full set of seven to make a randomly ordered list, can be interrogated in at least two distinct ways. One way is to present one of the weekdays and ask for a report of what followed it in the list, the other is to ask which day of the week was missing. These two methods call for distinctly different types of information; the former (or probe) method requires a knowledge of the order of items, the latter (missing item) method requires a judgement of familiarity of items. It turns out that irrelevant sound disrupts the probe version but not the missing item version: the disruption is, therefore, highly context-sensitive in the sense of happening only with some tasks.

From two perspectives, then, a factor related to the ordering of events seems to be at the heart of the distraction: the disruption only occurs if the brain needs to keep track of changing sounds, and it also only occurs if the order of events needs to be remembered in the focal task. So, it is not so much to do with how similar the to-be-ignored events are to the to-be-remembered ones, rather it is the similarity of processing of the two streams of mental activity.

One way to characterise these effects is to think of the setting as one where the problem is of selecting the right response from a range of those currently prevailing; this difficulty becomes more acute when the ignored events are plausible candidates – by virtue of the processing to which they are subject – for the focal skill of remembering in serial order. We refer to this as a 'conflict of process'. Notice that the degree of distraction cannot be predicted by considering either the character of the task or the character of the sound in isolation; it can only be understood by joint consideration of the obligatory processing of sound into ordered streams and the ordering process involved in the focal task.

Attentional Capture

That the sound needs to be changing in state for disruption to occur has been associated with a rather different interpretation of the effect of irrelevant sound, namely, that the effect of change is the result of successive episodes of 'attentional capture'. According to this view, attention is drawn involuntarily to an event if a mental model of the world of sound is violated: as we experience successive auditory events we build a 'mental model' of its characteristics, but any event that marks a sharp departure from that model commandeers attention away from the task at hand (thereby impairing efficiency). This suggests too that in the long run the impact of any irrelevant sound (as long as it has repeated elements) will be diminished by repeated presentation.

Whilst recent experimental work has shown convincingly that an unexpected deviation from an established pattern of sound does capture attention, and that this has a material impact on cognitive performance, there is also evidence that this mechanism does not underpin the 'changing state' effect we described earlier. Just as before, the verbal serial recall task was used, this time with sound sequences in which the established sequence was violated, for example, by presenting one irrelevant spoken item in a different voice from the remainder. Again, a drop in memory performance is observed, but this effect is not context sensitive: it happens just as much with the probe as the missing-item versions of the memory task (Hughes et al. 2007).

This strand of work has also been fruitful in further elucidating the nature of the mental model. One view is that the brain is quicker to build up a mental model if the sound is repeated than if it is not repeated; again, recent evidence has shown that

this is not the case: the effect of a deviant stimulus – such as a slight change in timing in a single member of the sequence – is just as great if it occurs in a sequence of changing letter-words or a repeated letter (Hughes et al. 2005). At the same time, these results show that the construct of 'habituation' has limited use in explaining these distraction effects, else the effect of the deviant would be more marked when it appears in a repeated than in a changing sequence. Other evidence also converges on the suggestion that habituation plays little role: typically, the impact of irrelevant sound does not diminish over the duration of an experiment (in which the exposure to irrelevant sounds and hence the opportunity for habituation would have been appreciable) nor does it diminish over successive days of testing (Hellbrück et al. 1996). This last set of findings is reassuring, insofar as it suggests that the distraction is not a fleeting phenomenon, but an enduring one, which suggests that it will have an impact in any setting outside the laboratory.

Although attentional capture does not underpin the changing state effect, it is nonetheless important to our understanding of the impact of single auditory events. Research on deviants is germane to the design of auditory alarms, for example (see Ljungberg et al. 2008).

The Vulnerability of Semantic Memory

For some time it seemed the effect on serial order was highly specific and that similar effects did not occur in other settings. Clearly, such an outcome would mean that the phenomena would be of limited generality and difficult perhaps to apply to everyday life. However, in just the last few years, evidence has emerged of low-intensity distraction in an apparently quite distinct domain: retrieval of semantic information. Here the emphasis is not on remembering the order of events, rather the dominant prevailing mental activity is remembering or retrieving words according to their meaning.

Figure 1 illustrated the point that for serial recall, the meaning of the speech has no effect. However, it is now apparent that meaning is important and can act as a distractor, but only if the focal task contains, and involves, the organisation of material by virtue of its meaning. This is in line with the idea that if the sound processing and the focal task processing are similar then distraction will occur. For example, if we present visually a list of (say, twenty) words whose membership is drawn from a few (say, four) semantic categories, such as 'fruits', 'animals' and so forth, we find that the number of words that can be recalled, as well as their coherence (typically measured by the degree to which the words are recalled not in the order in which they were presented but in clusters according to their meaning) is diminished in the presence of meaningful sound (Marsh et al. 2008a).

For this semantic distraction to occur, the similarity of the meaning of the to-be-ignored and to-be-remembered words is important, but this is not a direct product of the similarity of the words one to another; rather, it depends on the processing to which the to-be-remembered words are subject. Only if the focal task requires semantic processing will the semantic character of the to-be-ignored words be disruptive. If the self-same words in the focal task are processed and recalled in a non-semantic way, say just in the order in which they were presented, there will be no disruption from the semantic features of the irrelevant sound. Such effects occur as a result of 'conflict of process'. In the selection of the correct word, several competing words are in contention for production: words 'come to mind' that, while being plausible candidates, are not correct and some means must be found to inhibit their production. Our view is that in order to ensure that to-be-ignored sounds are not produced, they are inhibited but that this inhibition spills over so that it also impairs the

production of appropriate items. This would explain why the nature of the focal task processing is important and why the similarity in semantic content is important.

Another factor is also important in these settings, the extent to which the person can discriminate whether a word was heard or seen, or indeed generated 'internally' by the search through memory, namely their capacity to use source monitoring accurately. Indeed, this type of auditory distraction is one that has its roots in episodic memory, that is, memory for the time and place in which an event occurred. It is becoming clear that part of the difficulty of retrieving from memory is that individuals have difficulty in distinguishing whether they saw or heard the event. So, we have recently observed that the number of intrusion errors from the heard sequence of words also increases alongside the effect of the similarity of meaning of the heard to the to-be-remembered words (Marsh et al. 2008b). Such auditory distraction is particularly relevant to ear- and eye-witness testimony – the witness will have difficulty knowing the source of information if the irrelevant stream and the relevant one occur at the same time.

Finally, recent work has shown that these effects of semantic memory can occur in cases where no list is presented, in settings where participants are retrieving particular instances from their long-term memory. A typical task is one in which the participant is given a category (say, 'fruits'') and asked to retrieve as many words belonging to that category (the 'semantic fluency' task). Here again we witness a depression in performance if this is done in the presence of meaningful irrelevant sounds. However, asking for a different sort of retrieval, one not based on meaning (such as asking for words beginning with a particular letter – so-called 'phonemic fluency') is not susceptible to disruption (Marsh et al. 2008c).

CONCLUSIONS: HOW MANY VARIETIES?

Although on the face of it the effects in serial recall and in semantic memory appear distinct, we think this is illusory and instead believe they stem from a mechanism that acts to govern the selection of action. That is, the obligatory and 'sub-conscious' analysis of sound yields various sorts of information that can be used as the basis of action. When the results of this analysis are *compatible with, but inappropriate to, a* currently-prevailing skill, such as serial recall or retrieval involving semantic memory, they need to be inhibited in some way. What we witness in this type of auditory distraction is the price we pay for exercising control over this conflict of processing. This inhibition incurs a cost in maintaining the focal task and performance is damaged as a result. All this flows from the sentinel functional character of the auditory system; the obligatory access of sound to perceptual organisation and, indeed, higher cognitive analysis such as semantic processing (but not everybody agrees with this particular view: Carlyon 2004). At the same time, it should be acknowledged that this penalty for attentional flexibility must be weighed against the undoubted benefits of the organism having the general capacity to change the focus of attention adroitly in response to its adaptive needs. Although we can see a conceptual similarity between the results within semantic memory and serial recall, it is important to recollect that another, rather specific, mechanism is also involved in semantic memory retrieval: source monitoring.

Attentional capture, the effect of brief, infrequent, unexpected, sounds on cognitive performance seems to be a separate variety of distraction from that resulting from the conflict of process that we have just described. It is not the basis of changing state effects, but something that reflects an intrusion of attention – an 'interrupt-and-reorientate' mechanism if you will – that signals the need to abandon the current task

and seek information elsewhere. Again, for the most part, this is a highly adaptive function of the sentinel of the senses.

We began by noting the historical development of this area of study: it has moved away from the preoccupation with intensity and the associated constructs of behavioral arousal. Instead, most of the effects of low intensity sound are couched in terms of the obligatory organisation of sound and the relation of that processing to that in the focal mental activity. This requires a more thoroughgoing analysis of both the task and the auditory events but we are finding effects on performance at sound intensities and in tasks that were thought to be immune just a couple of decades ago. Attentional capture is the exception to this rule, however. The task of the future is to extend still further our catalogue of varieties and the settings in which they operate, as well as understand how these effects on performance influence such factors as annoyance and distress occasioned by sound. The picture is complex, but then again, nobody expected it to be easy.

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