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The Irrelevant Sound Effect: Testing the Psychological Effects of Sequence Predictability

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Abstract

We tested the hypothesis that expectancy-violation is key to understanding those conditions under which instrumental music disrupts immediate serial-recall. Using isochronic presentation of irrelevant-sound stimuli during encoding and retention, recall was found to be impaired following both piano-note sequences (Experiment 1) and pure-tone sequences (Experiment 2). However, whereas intervallic organisation was determinant for pure-tones (randomly-ordered frequencies caused recall impairment while repeated frequency or ascending-frequency sequences did not) there was no effect of intervallic organisation of piano-note sequences. When the to-be-ignored sequences were presented with random anisochrony, the disruptive effect was absent for both piano notes (Experiment 3) and pure tones (Experiment 4). It is proposed that the irrelevant sound effect can be explained in terms of stimulus specific expectancy violation.

KeyWords: Sound effect- Psychological effects of sequence predictability- violation of expectancy –memory performance in music

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Introduction

It is now well established that immediate serial-recall for visually presented stimuli can be impaired by the simultaneous presentation of auditory stimuli, even when participants are instructed to ignore them [1]. Although this irrelevant-sound effect has most commonly been investigated using speech sounds, a number of studies have reported that non-speech sounds can also impair memory [2- 5]. These latter studies have focussed almost exclusively on pure tones, whereas relatively little research has examined the effect of more complex auditory stimuli such as music. Boyle and Coltheart [6] reported that whereas all of the vocal conditions significantly reduced recall performance, the instrumental condition did not. So, if there are effects of music on memory, they appear to be relatively small when compared with the robust effects typically reported with irrelevant speech. Other studies have reported memory interference effects from vocal music Furnham. Why, when the effect of pure tones and speech have proved to be so robust, should instrumental music be so inconsistent in its effect? As a first attempt to answer this

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question, we begin by describing the main theoretical explanations of the irrelevant sound effect and the ways in which they can account for the data so far.Although not the first, Baddeley's model of the phonological-loop [7, 8] embodies the oldest contemporary account of the irrelevant sound effect. According to this model, speech or speech-like sounds will always have obligatory access to the phonological store in which to-be-remembered items are held prior to being retrieved. If only speech-like sounds were shown to interfere with memory there would be strong support for this hypothesis. However, this is clearly not the case since both pure-tones and white-noise have been shown to interfere [2, 4, 9]. In a computational implementation of the working memory model, Page and Norris [10] suggested an alternative mechanism by which irrelevant sounds might interfere with memory, within the framework of their primacy model. They proposed that the phonological store is represented by a subset of activated nodes whose strength of activation indicates the order of presentation. A simultaneously presented auditory sequence will activate an additional array of nodes, thus dividing attentional resources between the maintenance of the two sequences. In this implemented form, the working memory account overlaps with the key features of two other important explanations of the irrelevant sound effect, i.e. Cowan's attentional hypothesis [11, 12] and Jones' changing state hypothesis [13].

According to the model proposed by Cowan [11, 12], exposure to auditory stimuli results in the automatic construction, as a neural model. In this way, Cowan explains the common finding that sounds changing in frequency (changing-state sounds) tend to disrupt memory, whereas unchanging (steady-state) sounds do not [13]. There are a number of problems with Cowan's account, but the most problematic is the implicit prediction that the orienting response will habituate over trials, whereas the empirical evidence shows that it does not. Finally, there is the changing state hypothesis [13]. Like Cowan's model, the changing state hypothesis specifically addresses the common finding that only changing state sounds interfere with memory. However, rather than invoking an attentional mechanism, Jones and colleagues [13] suggest that the effect is due to a conflict between those seriation processes that are used to complete the memory task (irrelevant sound effects are most commonly reported in serial-recall) and those seriation processes that are automatically initiated whenever a changing sequence is perceived.

To our knowledge, the hypothesis that sequence unpredictability underlies the irrelevant sound effect has been explicitly tested only once. In their experiment, Jones et al. (1992) reported similar levels of disruption from either a repeated irrelevant consonant sequence (e.g. C, H, J, U, C, H, J, U etc.) or a random irrelevant sequence of the same consonants (e.g. C, J, U, H, J, U, C, H etc.). This effect is called "irrelevant speech effect". However , it is important at this point to differentiate between repetition and predictability. A simple illustration of this is to contrast

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repetition of the 26 letters of the alphabet in either a fixed-random order or in alphabetic sequence. Although the same items occur in both sequences, the latter sequence is more predictable (in this case, even without repetition), whereas after a number of complete repetitions the former sequence would still be difficult to predict. Hence, the irrelevant speech effect involves the same mechanism of the irrelevant sound effect. The difference between the two effects is the type of the sound: a note for the first effect and a word or syllable for the second.

In the musical cognitive literature, it has been established that violations of melodic expectancies are accurately detected by both musicians and non musicians [14], and there is evidence that such violations elicit automatic neural responses, as measured by ERP's [15]. So, there is good reason to suppose that conformity to expectation may account for the previous failures to find an irrelevant instrumental-music effect. In the following experiments, we examine the extent to which memory disruption from music may be due to the violation of a global algorithm (a sequence of piano notes should be anisochronic) based on musical expectancy (Tab. 1)

Tab.1

Experiment	Paradigm
1	**Irrelevant sound paradigm**
2	**Replication of Experiment 1, using pure tones in place of the piano notes**
3	**Irrelevant sound paradigm with a change of the timing of the presentation**
4	**Irrelevant sound paradigm with a rhythmic variation**

Experiment 1

In our first experiment, we utilized an irrelevant sound paradigm based on the results of Hughes et al. [16] in which a sequence of digits to be remembered is synchronously presented with an equal number of auditory stimuli during encoding, followed by the same number of auditory stimuli presented during the retention phase. Since we were interested in those characteristics of music that might interfere with memory, we initially chose a sequence of piano notes as the to-be-ignored stimuli. However, in addition to the traditional changing-state (random item sequence) and steady-state (single repeated-item) conditions, we examined the effects of a new condition, an ascending sequence of piano notes.

Methods

Participants

Twenty four undergraduates (23 females and 1 male) from the Catholic University, Milan, took part in this experiment. Their ages ranged from 19 to 31 years (mean age = 23.21, *SD* = 4.35).

Materials and Design

The irrelevant sounds consisted of two complete octaves (24 semitones) of synthesised piano

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notes from C1 to A2. The to-be-remembered stimuli consisted of 88 lists (including 8 practice lists), each of which contained a random ordering of the digits 1 to 8. These lists were divided into four equal sets and each set appeared in one of four conditions: silence, steady-state sound (a single, randomly selected - among the 24 semitones - note, played sixteen times), ascending sound (sixteen notes played in ascending order, beginning from a random initial note between C0 and G0) and random sound (a random sequence of sixteen notes, selected without replacement). Conditions were manipulated within participants and the order of presentation of conditions was blocked and counterbalanced such that they appeared in every possible order. Each piano note in the irrelevant sound sequence had a duration of 500 msec and was followed by 500 msec of silence. The eight to-be-remembered list items were presented visually in the centre of the screen in 100 point Geneva font. As in Hughes et al. [16] onset of each visual stimulus was synchronised with the onset of the irrelevant sound. Each visual stimulus was displayed for 500 msec followed by a blank screen for a further 500 msec. Presentation of the last stimulus was followed by a retention interval of eight seconds, during which the screen remained blank while the sounds continued.

Procedure

Participants were seated in front of an Apple Macintosh G3 computer in a quiet room and asked to read a set of on-screen instructions. They were informed that they would be presented with a series of digits that they should try to recall in sequence and that they should ignore any sounds they heard over a pair of headphones. They were also informed that the first two trials of each block were practice trials. The trials were self-paced and initiated by the participant pressing the space bar on the computer keyboard. Following presentation of each list, a series of eight boxes appeared, equally spaced across the screen from left to right. Participants used the keyboard to enter their responses that in turn appeared sequentially in the eight boxes. They were told that if they could not remember a particular item that had appeared in a particular position, they were to type the numeral ‘0’ that would appear in the appropriate box as a place marker. Participants were also told that it was not possible correct mistakes and if they did make a mistake they should simply continue. Although there was no time limit set for the recall phase, participants were asked to respond as quickly and accurately as possible. Participants took between 45 and 50 minutes to complete the task.

Results

Mean recall scores were calculated for each serial-position in each condition. There were significant main effects of sound condition, $F(3, 69) = 4.547$, and of serial-position, $F(7, 161) = 41.292$, but no interaction between the two, $F(21, 483) = 1.019$. It is clear that participants

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performed better in silence than in any of the three irrelevant-sound conditions and this was confirmed by planned comparisons that showed that all three conditions differed significantly from silence; steady state, $F(1, 23) = 8.980$; random, $F(1, 23) = 7.453$; ascending, $F(1, 23) = 11.138$.

Discussion

At first, this appears to be a rather curious finding. Despite previous reports of the effect of instrumental music on memory have been ambiguous, we were expecting to find at least a changing-state effect, i.e. that randomly presented sounds would interfere more than a single repeated sound (which itself forms a predictable sequence). Although it is unusual for steady-state sounds to interfere, this finding is not unprecedented and a number of authors have reported significant interference from steady-state irrelevant. Within the changing state hypothesis, such steady state effects have been ascribed to transitional changes between the initial silence and the onset of the irrelevant sound stimulus, though this could not explain the equivalent effects of steady and changing state. In fact, we are aware of only one report in which steady-state sounds interfered with memory to the same extent as changing state [17].

At this point, it is worth making some comparisons between our design and those of other researchers. As we noted in the introduction to Experiment 1, the design was modelled on that of Hughes et al. [16] who reported a typical changing-state effect (sequentially-random sounds caused more disruption than either a repeated sound or silence) and no significant effect of regularly presented steady-state sound on recall. One small difference between our study and theirs was that they used perceptual synchronisation of the visual and auditory stimuli (the onset of each auditory stimulus was 75 msec before the onset of the corresponding visual stimulus) whereas we used physical synchronisation. Unfortunately, there is not always sufficient detail reported in other studies to know if onset of the two types of stimuli was synchronised.

Another potentially important factor is the dose of irrelevant sound since it is known that the more times a sound is perceived to change, the larger is the disruption . However, once again, there is adequate evidence that sixteen auditory stimuli (as used in this experiment) are sufficient to produce the standard pattern of the irrelevant sound effect. For example, Hughes et al. [16] found a changing state effect with 16 sounds while Le Compte [18] found a significant changing state effect with only 9 tokens.

In light of the above discussion, it seemed logical to focus on the most obvious differences between our findings and those previously reported, i.e. the choice of to-be-ignored stimuli. Since all other studies have used either vocalisations or pure tones, rather than notes produced by a musical instrument, it seemed prudent to replicate the experiment using pure tones.

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If the results of the experiment 1 were due to some particular aspects of our design or procedure that we had yet to discover, we would expect to find results similar to those for musical notes.

Experiment 2

This was essentially a replication of Experiment 1, using pure tones in place of the piano notes.

Results

There were significant main effects of sound condition, $F(3, 69) = 2.915$, and serial-position, $F(7, 161) = 30.580$, as well as a marginally significant interaction between the two, $F(21, 483) = 1.577$, $p = .05$. Planned comparisons revealed no performance difference between the steady-state and silent conditions, $F(3, 69) = .510$, nor between the ascending tone and silent conditions, $F(3, 69) = 4.038$ ($p = .056$). Only performance in the changing state condition differed significantly from that in silence, $F(3, 69) = 5.690$. The finding that changing-state (random) tones impaired recall performance, whereas steady-state tones did not, is consistent with a large body of data. However the discovery that ascending tones did not significantly disrupt recall performance is something new. We will consider the impact of this finding in more detail in the General Discussion, but for the moment we wish to underline the fact that by differing only the type of auditory stimuli between Experiments 1 and 2, we have obtained very different results.

Experiment 3

Given that we found a disruptive effect of irrelevant piano notes in all conditions, it was clear that we had yet to isolate that variable responsible for previous failures to find an effect of irrelevant music. We elaborate the strong version of the expectancy violation hypothesis in this third experiment. If complex patterns of rhythm are expected and not found, this may be sufficient to divert attentional resources toward the irrelevant sound. On the other hand, if rhythm is expected and found, the disruption should be far less. We explored these issues by introducing irregularity into the presentation of our piano notes.

Method

Participants

There were 24 undergraduates (22 females and 2 males) from the Catholic University, Milan, non of whom had taken part in any other experiments in this series. Ages ranged from 19 to 24 years (mean age = 21.58, *SD* = 1.02).

Materials and design

Materials were the same as those used in Experiment 1. The design was similar to Experiment 1, but differed only in the timing of presentation of the irrelevant sounds. For all irrelevant-sound conditions, the onset of each sound was preceded by a silent interval of 200, 400, 600 or 800 msec. (each silent interval was selected twice such that one of the four intervals preceded each of

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the sixteen sounds played in each trial) thus the mean-interval between the sixteen sounds (500 msec.) was equivalent to the ISI in the regular-presentation conditions of Experiments 1 and 2.

Procedure

The procedure was the same as for Experiment 1.

Results and Discussion

Although the main effect of serial position was significant, $F(7, 161) = 19.619$, there was no main effect of sound condition, $F(3, 69) = 0.598$, and no interaction between the two, $F(21, 483) = 1.020$. It can also be noted that the range of scores across serial-position is very similar in all three experiments (all within the range from about 40% to 90%) suggesting that the differences between the two experiments were not due to either floor or ceiling effects. If the stimulus fails to match the expectancy for these types of stimuli, then the irrelevant sound becomes relevant and attentional resources are automatically re-directed.

Experiment 4

It was interesting to know how performance would be affected when pure-tone irrelevant sounds are presented with a rhythmic variation.

Methods

Participants

A total of 24 participants with ages ranging from 19 to 42 (mean = 24.63, S.D. = 6.33). There were 21 females and 3 males. All were undergraduates at the Catholic University, Milan.

Materials and Design

Materials were the same pure-tones used in Experiment 2 and the design was the same as that reported in Experiment 3, with the same variable timing of presentation of the irrelevant sounds.

Procedure

The procedure was the same as for Experiment 1.

Results

Only the main effect of serial position was significant, $F(7, 161) = 40.046$. There was no significant main effect of sound condition, $F(3, 69) = 1.110$, and no interaction, $F(3, 69) = 1.068$.

General Discussion

In our four experiments, we have demonstrated how the violation of a higher order global algorithm (i.e. the expectation of a sequence of sounds) can disrupt memory performance. Moreover, violation of this expectancy for instrumental notes was apparently strong enough to swamp the differential effects normally reported between changing-state and steady-state sounds (Experiment 1). However, the commonly reported finding that changing-state tones disrupt memory performance more than steady-state tones were supported in our Experiment 2 and this

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difference between pure and instrumental tones suggests that the expectancy of rhythm is different in the two types of stimuli. Further support of this difference came from Experiment 2 in which we reported the novel finding that an isochronic sequence of ascending tones did not disrupt memory performance, in spite of fitting the profile of changing state stimuli. The one shared characteristic of piano notes and pure tones that was neither caused disruption when presented with a random temporal variation (Experiments 3 and 4).

As we have already described in the introduction, this the attenional hypothesis in its original form [11, 12] had a number of fatal problems. However, it is the adapted form described by Hughes et al. [16] that has driven our experiments and so we describe how this version of the attentional hypothesis can account for our data. Hughes et al. [16] suggested that attention is captured only by sounds that deviate from an algorithmic model, i.e. an expectation of a sequence of sounds constructed from rules that can be established either globally (e.g. the items will ascend in canonical order) or locally (e.g. each item will be different from the previous one). In either case, a deviation from the rule (e.g. a missing item in the former or a repeated item in the latter) will result in the diversion of attentional resources. In their study, Hughes et al. [16] found that a temporal deviant (a single item that occurred unexpectedly late or earlier within an otherwise regularly presented list) was sufficient to cause disruption to serial recall.

Since our primary hypothesis was based on a violation of expectancy, it had been a relatively simple matter to make predictions with regard those musical expectancies that might be important. In this respect, the findings of Experiments 1 and 3, both using piano notes, lead us to believe that tonal intervals are unimportant in determining attentional capture from music, perhaps because there is often an expectation for a complex intervallic structure. In neither experiment did we find evidence of the changing state-effect usually reported for both pure tones [13] and speech [18]. Moreover, in Experiments 1 and 3, we found that it was of no consequence if the piano note sequence followed a predictable pattern (ascending notes) or a non predictable pattern (random notes).

However, in spite of a number of earlier experiments using irrelevant tones, Experiment 4 was the first to report that the irrelevant tone effect can be eliminated by introducing irregularity in inter-stimulus interval. The simplest explanation would be to consider that tones presented with rhythmic variation are interpreted as music, whereas in the absence of rhythm, the tones are interpreted simply as electronic sounds. The latter case may lead to the reasonable expectation of a simple, predicable structure, since such sounds would be most commonly produced with an automated device such as a computer [19, 20]. In this respect, we can make sense of the finding that an ascending isochronic sequence of pure-tones do not disrupt memory, whereas an

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isochronic sequence of randomly pitched pure-tones does.

We are confident that we have found further support for the hypothesis that violation of an algorithm-based neural model can result in a decrement in recall performance. Specifically, we have demonstrated how this might be applied to the previously ambiguous findings related to memory performance in music [6] and in so doing, we hope that we have provided new impetus to an old puzzle. We have begun the process of determining the specific nature of some of those algorithms in a way that we anticipate will stimulate a considerable body of future research.

Conflicts of Interest: The authors declare no conflict of interest and no source of funding for the present research.

Disclaimer: All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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