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The Impact of Order Incongruence Between a Task-Irrelevant Auditory Sequence and a Task-Relevant Visual Sequence

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A novel effect is reported in which serial recall of visual digits was disrupted to a greater degree by the presence of the same set of digits presented as an irrelevant auditory sequence than by the presence of irrelevant auditory consonants, but only when the order of the irrelevant digits was incongruent with that of the to-be-remembered digits (Experiment 1). Experiment 2 replicated this *order-incongruence effect* and showed also that disruption was dictated by the number of order-incongruent transitions but not by the number of novel tokens contained within the irrelevant sequence. The results favor an *interference-by-process* approach to the disruption of serial memory by irrelevant sound over approaches based on notions of *interference by content* and/or *interference by depletion of attentional resources*.

It is generally recognized that a selective attention system is required to ensure that only incoming information that is relevant to the current immediate goal assumes the control of behavior (e.g., Allport, 1989, 1993; Broadbent, 1958; Duncan, 1980; Houghton & Tipper, 1994; Neumann, 1987, 1996; Treisman, 1964). However, attentional selectivity is clearly not "perfect" or "complete," as evidenced by numerous phenomena in which task-irrelevant information interferes with goal-directed action (e.g., Broadbent, 1958; Colle & Welsh, 1976; Eriksen & Eriksen, 1974; Jones, 1999; Stroop, 1935; Tipper, Howard, & Jackson, 1997; Treisman, 1964; Yantis, 1998). One such phenomenon is the irrelevant sound effect, the disruptive impact of to-be-ignored auditory information on visual–verbal serial recall (e.g., Colle & Welsh, 1976; Jones & Macken, 1993; LeCompte, 1994; Neath, 2000; Salamé & Baddeley, 1982, 1989). The question addressed in the present study was this: Do irrelevant auditory–verbal items taken from the same set used for the relevant visual to-be-remembered sequence produce greater interference than irrelevant items taken from a different set? The answer to this question would aid in adjudicating between three competing approaches to the irrelevant sound effect, each of which is underpinned by a distinct view of the nature of attentional selectivity and interference between competing stimuli. We turn first to describe the main features of the irrelevant sound effect.

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Irrelevant Sound Effect

The irrelevant sound effect refers to the marked reduction in the serial recall of a list of (usually visually presented) items (e.g., eight or nine digits) in the presence of background sound that the participant is instructed to ignore compared with performance in a quiet control condition. Several key findings now command a degree of consensus: The intensity of the sound is not an influential variable (at least within the range of 40–76 dB[A]; Colle, 1980; Tremblay & Jones, 1999), the interference occurs at a postencoding stage of processing (i.e., it is not due to some kind of sensory or perceptual masking or confusion between relevant and irrelevant items during the encoding of the to-be-remembered items; e.g., LeCompte, 1994; Macken, Mosdell, & Jones, 1999; Miles, Jones & Madden, 1991; Neath, 2000; Salamé & Baddeley, 1982), and meaning—such as might be extracted from irrelevant narrative speech, for example—also plays little if any role in this effect (Buchner, Irmen, & Erdfelder, 1996; Colle & Welsh, 1976; Jones, Miles, & Page, 1990; Salamé & Baddeley, 1982; but see Neely & LeCompte, 1999).

The necessary and sufficient condition for marked disruption is that the irrelevant sound sequence must exhibit some acoustical variation (the *changing-state effect*; Jones, Madden, & Miles, 1992). This generalization holds whether speech tokens (e.g., "c, j, t, u" as opposed to "c, c, c, c") or nonspeech tokens (e.g., successive tones changing in frequency compared with the same tone repeating; Jones & Macken, 1993) are used. Moreover, tasks that involve seriation—the retention and production of order information—are particularly susceptible to interference, whereas tasks that are not so reliant on seriation are relatively immune (Baddeley & Salamé, 1986; Beaman & Jones, 1997, 1998; Boyle & Coltheart, 1996; Burani, Vallar, & Bottini, 1991; Jones & Macken, 1993; Richardson, 1984; Salamé & Baddeley, 1990). We turn now to consider three theoretical approaches to the irrelevant sound effect.

Interference by Content

One approach to the irrelevant sound effect supposes that the disruption is due to *interference by content*—that is, it is a function of the similarity in the identity of the irrelevant and relevant stimuli. This approach is underpinned by the broader view that interference between competing stimuli occurs to the extent that some discrete, limited-capacity module or memory store becomes overloaded, a view most famously embodied in Broadbent's (1958) filter theory (see Neumann, 1996). For example, the *phonological-confusion* account (Salamé & Baddeley, 1982, 1989), based on the working memory model (e.g., Baddeley, 1986), proposes that "it is the *degree of phonological similarity* between the irrelevant material and the memory items that underlies the irrelevant speech effect" (Gathercole & Baddeley, 1993, p. 13). That is, representations of phonemes in the irrelevant sound gain obligatory access to a short-term phonological store wherein they can become confused with similar phonemes associated with the to-be-remembered items that have gained access to the same store via a grapheme-to-phoneme conversion process. However, this account fails to accommodate a range of empirical results (see Jones, Macken, & Nicholls, 2004). These include the finding that nonspeech irrelevant sound can produce an irrelevant sound effect (e.g., Jones & Macken, 1993) and the finding that the degree of phonological similarity between the sequences does not in fact—despite some early evidence to the contrary (Salamé & Baddeley, 1982)—dictate the degree of disruption (Jones & Macken, 1995; Larsen, Baddeley, & Andrade, 2000; LeCompte & Shaibe, 1997).

A more recent account, based on a computational *feature model* of immediate memory (Nairne, 1990), also posits that the interference is, in part, due to interference by content (Neath, 2000). More specifically, if the irrelevant and relevant items have modality-independent features in common (features not tied to the modality of presentation such as phonology, categorical identity, etc.), primary memory traces of to-be-remembered items will tend to adopt corresponding features from the irrelevant items. Thus, if the value of Feature A of a given irrelevant item differs from the value of Feature A in a concurrently presented or rehearsed to-be-remembered item, the trace of that to-be-remembered item will tend to be corrupted. This *feature-adoption* process in turn reduces the likelihood that the correct match will be found for each primary memory trace in secondary memory from which item information is ultimately retrieved.

In isolation, the feature-adoption mechanism in the feature model does not provide a way to simulate what can, arguably, be dubbed the two clearest empirical signatures of the irrelevant sound effect, namely the changing-state effect (e.g., Jones et al., 1992; see Beaman, 2000) and the fact that nonspeech sounds can produce disruption of serial recall (Jones, Alford, Bridges, Tremblay, & Macken, 1999; Jones & Macken, 1993; Tremblay & Jones, 1998; Tremblay, Macken, & Jones, 2000). To simulate these effects, the feature model requires the supplementary parameter a, which, according to Neath (2000), "can be mapped onto the overall level of attention or available resources" (p. 408). That is, the presence of irrelevant sound (speech or nonspeech), and particularly of changing-state sound, is deemed to produce a dual-task situation such that the second task (ignoring the sound) depletes some "processing resource" called "attention" (see also Cowan, 1995; Elliott, 2002). Thus, although the model, through adjustment of an "attentional parameter," can simulate these key effects, reservations must be expressed about using the "attentional component" to generate particular predictions. This is because the model does not specify what independently verifiable empirical referents could be used to check, a priori, the degree to which "attentional resources" will be depleted by a given irrelevant sound manipulation.

Interference by Depletion of Attentional Resources

The feature model is not alone in using the attention-as-resource construct; several suggestions have been made to the effect that the irrelevant sound depletes some attentional resource (e.g., Kahneman, 1973; Wickens, 1984) required to perform the primary task, and some models use this as the sole device for explaining the disruptive effect of irrelevant sound (Cowan, 1995; Elliott, 2002). One elegant and parsimonious version of the *attention-as-resource* approach invokes habituation of an orienting response (OR) as the main explanatory mechanism (cf. Näätänen, 1992; Sokolov, 1963). That is, a changing-state sequence may be more generally "distracting" because the novelty of each successive item elicits an involuntary attentional OR, whereas such a response quickly habituates if the sequence is relatively devoid of novelty (as in a steady-state sequence). However, there are several observations in the irrelevant sound literature that are problematic for the *habituation-of-the-OR* account (see Jones & Tremblay, 2000). For example, given that orienting is thought to be triggered by novelty rather than by the change between items per se (see Cowan, 1995), the degree of disruption should be a positive function of the number of novel items encountered over the course of the irrelevant sequence. However, it has been shown that having two novel tokens in the irrelevant sequence ("a, b, a, b, a, b, a, . . .") is as disruptive as having five novel tokens ("a, b, c, d, e, a, b, . . ."; Tremblay & Jones, 1998; but see Campbell, Beaman, & Berry, 2002). Thus, models that rely on an attention-as-resource construct to account either for some or for all aspects of the irrelevant sound effect either are underspecified at present (Neath, 2000) or, if better specified (Cowan, 1995), fail to accommodate some key characteristics of the effect (see Jones & Tremblay, 2000). This disaffection with the *depletion-of-attentional-resources* approach to the irrelevant sound effect resonates with that felt generally about the conceptualization of attention as some limited processing resource or set of resources (e.g., Allport, 1987, 1989, 1993; Navon, 1984; Neumann, 1984, 1987, 1989, 1996; Robinson, 2003; Sanders, 1998; Van der Heijden, 1992).

Interference by Process

The *interference-by-process* account of the irrelevant sound effect posits that the acoustical mismatches between the successive auditory stimuli in a changing-state irrelevant sequence yield cues representing their order (e.g., Hughes & Jones, 2001, 2003a, 2003b; Jones, 1993, 1999; Jones, Beaman, & Macken, 1996; Macken & Jones, 2003). On the basis of the auditory scene analysis framework (Bregman, 1990), it is thought that these order cues are a byproduct of the preattentive process of integrating successive stimuli into a coherent perceptual stream, despite the fact the sequence exhibits some degree of acoustical variation. It is further assumed that the irrelevant order cues clash with the process of seriating the to-be-remembered items during rehearsal in support of serial recall (Jones et al., 1996). This account is therefore allied to the broader viewpoint that interference between competing stimuli is a function of the degree to which the irrelevant information will compete with the relevant information for the control of action (e.g., Allport, 1989; Neumann, 1987, 1996). Thus, on the interference-by-process account, interference from irrelevant sound is not a function of the particular content of the irrelevant and relevant material, and it can therefore easily accommodate irrelevant changing-state nonspeech effects. Neither does the account posit that the sound disrupts recall by drawing "attentional resources" away from the storage of to-be-remembered items. The interference-by-process account therefore explains why tasks involving seriation are far more susceptible to interference, and it also explains a range of subtler effects reported in the literature (Hughes & Jones, 2001; Jones & Tremblay, 2000).

Present Study

The primary determinant of the irrelevant sound effect seems to be a conflict between similar processes, and having similar content within the irrelevant and to-be-remembered sequence is certainly not necessary to produce the effect. Moreover, a depletion-of-attentional-resources approach fails to provide a satisfactory explanation for a range of empirical results. However, there is one line of evidence that might, at first glance, be taken to indicate that presenting irrelevant and relevant items that are similar in content might at least exacerbate the degree of disruption. As noted, a similarity between the relevant and irrelevant sequence in terms of the phonemes each contains does not augment the degree of disruption (Bridges & Jones, 1996; Jones & Macken, 1995; Larsen, Baddeley, & Andrade, 2000; LeCompte & Shaibe, 1997). However, there is mixed evidence regarding whether a condition in which the irrelevant and relevant items are lexically identical produces more disruption than a condition in which the two sets of items are unrelated. For example, in a study by Salamé and Baddeley (1982, Experiment 5) in which the to-be-remembered sequences were permutations of the digits 1–9, presenting the same set of (*identical*) words as irrelevant auditory items (i.e., "two, five, one . . .") caused reliably more disruption than presenting *unrelated* disyllabic words (e.g., "tipple, jelly, wicket . . ."). Jones and Macken (1995) found that the disruptive effect of identical items was statistically reliable for two out of seven to-be-remembered items, and there was a trend in the same direction for three of the remaining five to-be-remembered items. In contrast, Bridges and Jones (1996) did not find any evidence that identical items were more disruptive than unrelated items.

Let us assume that identical irrelevant items do produce reliably more disruption than unrelated irrelevant items. The phonological-confusion account (Salamé & Baddeley, 1982) might suppose, although it is not clear what the precise mechanism would be, that phonological confusion, and therefore interference, is particularly likely to occur when the individual phonemes from the relevant and irrelevant items are not only identical but are associated with the same lexical items. In contrast, the feature model (Neath, 2000), through its feature-adoption construct, does not necessarily predict more interference from identical irrelevant items than from unrelated irrelevant items because, as mentioned, it is the adoption of feature values that differ from those already contained within a given to-be-remembered trace that corrupts the retrievability of that trace. For example, if digits were used as to-be-remembered items, in the identical condition—because the covert rehearsal, if not the presentation, of each visual digit is likely to coincide temporally with irrelevant digits that do not match it (e.g., *3* might be presented or rehearsed while "eight" is being heard)—irrelevant digits would not necessarily be expected to corrupt the traces of to-be-remembered digits any more than would unrelated irrelevant items (e.g., consonants; see Neath, 2000). However, if it transpires that identical items are more disruptive than unrelated items, the feature model may be able to accommodate this outcome by appealing to its "attentional component." However, this would only be by virtue of the lack of specification of this component; it is unclear by what specific mechanism identical items would draw more attentional resources from the primary task than would unrelated items.

The better specified habituation-of-the-OR account (Cowan, 1995; Elliott, 2002) would seem to predict no difference between identical and unrelated conditions. This is because any two irrelevant sequences that are roughly comparable in terms of the number of acoustically novel items they contain should interfere with recall to a similar degree, and there is no reason to expect identical and unrelated items to differ in this regard.

Similarly, the interference-by-process account would not, at first glance, predict that identical irrelevant items would be more disruptive than unrelated irrelevant items. That is, the level of interference should simply be a function of the extent to which the irrelevant sound generates order information, and there is no reason to assume that identical and unrelated irrelevant sequences should differ in this respect. However, in each of the previous experiments that have compared identical and unrelated conditions, although the irrelevant and relevant items were identical, the order in which they were presented within the irrelevant and relevant sequence on each given trial would have been different. Thus, an extension of the interference-by-process account may provide a way of accommodating greater disruption from identical compared with unrelated items. Specifically, in a condition in which the order of the items in each sequence is different, the preattentively generated auditory order information would constitute information that is highly congruent with the specific category of action demanded by the task (the seriation of a particular set of verbal items) but would, at the same time, be incongruent with the specific action demanded by the task—namely, to serially rehearse and recall only the to-be-remembered sequence. The present experiments (a) sought to establish whether the irrelevant sound effect is indeed exacerbated when the irrelevant and relevant sequences contain the same lexical items and (b) addressed for the first time whether any additional disruption observed is driven by the fact that the individual items in each sequence are identical per se or by the fact that they are presented in different orders.

Experiment 1

In Experiment 1, we contrasted the capacity to serially recall permutations of the digit set 1–8 in conditions in which the irrelevant and to-be-remembered items were (a) identical but presented in different orders (*digits-incongruent order condition*), (b) identical but presented in such a way that the orders of the two sequences were largely congruent (*digits-congruent order condition*), and (c) unrelated (the irrelevant auditory items were consonants in this case). A *quiet* control condition was also included.

An *order-incongruence* effect—that is, poorer performance with irrelevant digits than with irrelevant consonants, but only when the order of the digits is incongruent with that of the to-be-remembered digits—would be most readily explicable in terms of an interference-by-process approach to the irrelevant sound effect. A more general *identical-set effect*, however—that is, poorer performance when the irrelevant items are digits than when they are consonants, regardless of whether the order of the digits is incongruent with that of the to-be-remembered digits—would be more consistent with the phonological-confusion account (Salamé & Baddeley, 1982). Predictions from the feature model are complicated by the fact that two explanatory mechanisms—feature adoption and changes in the levels of "attentional resources"—can be used interchangeably and the model fails to specify the conditions under which they will be deployed. If, for the moment, we take the simplifying step of excluding the "attentional component," no difference should be expected between the impact of unrelated and related items, irrespective of whether the related items are presented in an order that is incongruent with that of the to-be-remembered items. Again, however, if identical items are found to be more disruptive than unrelated items only in the incongruent-order condition, the feature model may still appeal to its "attentional component" to accommodate such an effect. Finally, according to the habituation-of-the-OR account (e.g., Cowan, 1995), there is no reason to expect identical items to be more disruptive than unrelated items and, therefore, no reason to expect the disruptive potency of the identical irrelevant items to vary according to whether they are presented in an order that is incongruent with the to-be-remembered items.

Method

Participants

Thirty-two undergraduate psychology students at Cardiff University, Cardiff, Wales, United Kingdom, all reporting normal or corrected-to-normal vision and normal hearing, took part in the experiment in return for course credit. All were native English speakers.

Apparatus and Materials

To-be-remembered list. The primary serial-recall task involved the visual presentation of eight digits (taken from the set 1–8 without repetition of any one digit), presented one by one at the center of a computer screen in a 72-point Times font. For each trial, the order of the digits was determined pseudorandomly, with the constraint that ascending or descending runs of three or more were avoided. Each digit remained onscreen for 350 ms, and the interstimulus interval (ISI; offset to onset) was 400 ms.

Irrelevant auditory items. In the three irrelevant sound conditions, the eight visual digits were accompanied by a sequence of eight spoken digits or by a sequence of eight spoken consonants. Thus, one set of spoken digits ("one"– "eight") and one set of spoken consonants ("b," "h," "j," "k," "l," "m," "q," and "s") were recorded in a female voice at an approximately even pitch. Each item was then digitally edited so as to last 250 ms. The ISI (offset to onset) in an irrelevant auditory sequence was 500 ms. The onset of each of the eight auditory items preceded each of the eight visual digits by 75 ms to produce approximate phenomenal cross-modal simultaneity. The visual and auditory stimuli were presented using PsyScope (Version 1.2.5) software (Cohen, MacWhinney, Flatt, & Provost, 1993) running on a Macintosh Performa computer.

Design

A repeated measures design was used with two factors: auditory condition (four levels; quiet, consonants, digits-congruent order, and digits-incongruent order) and serial position (eight levels). Figure 1 is a schematic illustration of how the four auditory conditions were generated. The consonants condition simply involved presentation of the eight consonants in a random order for each trial. Most important to note is that the digits-congruent order condition was generated by having the same sequence of digits as to-be-remembered and irrelevant material but staggering the sequences by two serial positions. As such, the concurrently presented to-be-remembered and irrelevant digit never matched, yet all but one of the conjunctions or transitions between temporally adjacent items in the irrelevant sequence also occurred in the to-be-remembered list. Note that the only transition present in the irrelevant sequence but not in the to-be-remembered list ("two"–"five" in the example in Figure 1) still does not conflict with any transition in the to-be-remembered list, because *2* and *5* appear at each end of the to-be-remembered list. In contrast, in the digits-incongruent order condition, all transitions are different from those in the to-be-remembered concurrent sequence (it was also ensured in this condition that the concurrently presented to-be-remembered and irrelevant digits were never the same digit). In addition to these constraints, for both irrelevant-digit conditions, it was ensured that there were no ascending or descending runs of three or more digits either within the irrelevant sequence or across the irrelevant and concurrent to-be-remembered sequences.

There were 17 trials in each condition except for the consonants condition, in which there were 34, making 85 trials in all. There were twice as many trials in the consonants condition than in the two conditions featuring irrelevant digits so that the number of trials with irrelevant consonants equaled the number featuring irrelevant digits. The conditions were presented in a pseudorandom order in a single block of experimental trials, with the constraint that each condition was presented once per 5 trials (except for the consonants condition, which was presented twice every 5 trials).

Procedure

Participants were tested individually in a soundproof booth and were seated at a distance of approximately 0.5 m from the screen. Each participant first read standard instructions informing them of what the task involved and instructing them to ignore any speech they might hear through the headphones. Participants were also informed that the trials would be presented at a preset pace: 50 ms following the offset of the last visual item, the screen flashed from white to black for 150 ms, which signaled to the participant that he or she should begin to write out the list. From the offset of the screen flashing, there were 16.5 s before the presentation of the first item of the next to-be-remembered list. A 500-ms tone was presented over the headphones 13 s into the 16.5 s of "writing time" to signal to the participant that the presentation of the first item of the

To-be-remembered items (visual):	**5 1 7 3 8 4 6 2**
Auditory condition:	
1. Quiet:	----------------------
2. Consonants:	**b h j k l m q s**
3. Digits-congruent order:	**6 2 5 1 7 3 8 4**
4. Digits-incongruent order:	**7 4 1 5 3 2 8 6**

Figure 1. A schematic illustration of how the four auditory conditions in Experiment 1 were generated. Note that the particular order of the digits in the to-be-remembered sequence and the particular order of the irrelevant items in the digits incongruent condition that appear in this figure are just possible examples of sequences that could have been presented in the experiment. (Details of the pseudorandomization process used in the procedure are given in the text.)

next sequence was imminent. Two practice trials, one from the consonants condition and one from the digits-incongruent order condition, were undertaken before the experiment proper. The experiment lasted 40 min. Following the experiment, participants were asked whether they had noticed any particular relationship between the to-be-remembered and the irrelevant sequence at any time during the experiment. This question was designed to examine whether participants had become explicitly aware of the incongruent-versus-congruent manipulation. The hope was that most participants would not become so aware, because such awareness could potentially lead to a strategic use of the nominally irrelevant information to aid in recall of the to-be-remembered items in the digits-congruent order condition, thereby muddying the interpretation of any difference in performance that might be obtained between this condition and the digits-incongruent order conditions.

Results

We scored the raw data according to a strict serial-recall criterion: An item had to be recalled in the same position as that in which it was presented to be counted as correct. Figure 2 shows the percentage of items correctly recalled in each of the four auditory conditions. There is clear evidence of a substantial classical irrelevant sound effect; performance was far poorer in all the irrelevant sound conditions compared with the quiet condition. More interesting, although all of the irrelevant sound conditions produced an irrelevant sound effect, performance in the digits-congruent order condition was broadly similar to that in the consonants condition. The digits-incongruent order condition, however, depressed performance still further. In sum, there was a strong irrelevant sound effect that was exacerbated by having identical irrelevant and to-be-remembered items, but, critically, this additional interference only obtained when the order of the identical items in each sequence was incongruent.

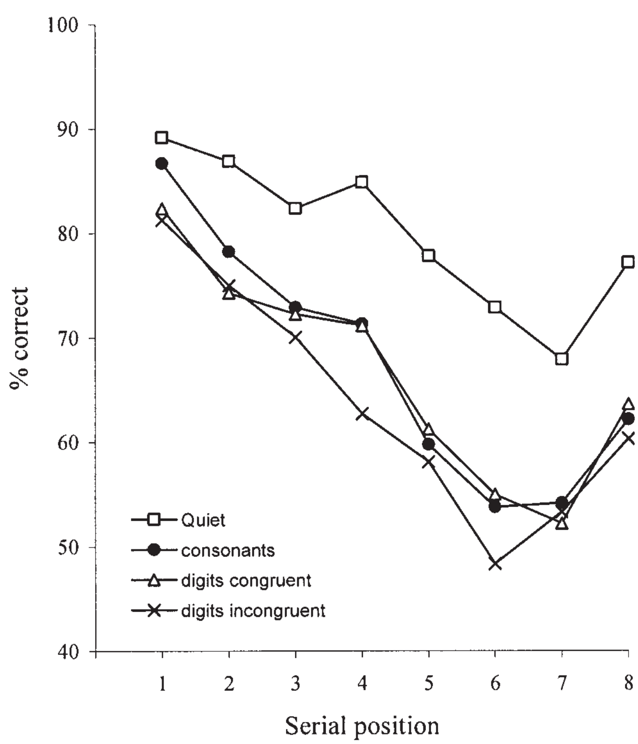

Figure 2. Mean percentages of items correctly recalled in the quiet, consonants, digits-congruent order, and digits-incongruent order conditions in Experiment 1.

We analyzed the data both with all 32 participants' data included and with only the data from the 21 participants who were categorized as *unaware* of the *congruence-versus-incongruence* manipulation. The critical aspects of the results were the same for unaware participants as they were for the sample as a whole. Nonetheless, in the report of the analyses below, the statistics for the analysis of variance (ANOVA) for all 32 participants is followed in parentheses with the statistics for the ANOVA for only the 21 unaware participants.

A repeated measures ANOVA revealed a main effect of auditory condition, $F(3, 93) = 26.11$, $MSE = 422.41$, $p < .001$ (unaware: $F[3, 60] = 17.49$, $MSE = 349.50$, $p < .001$); a main effect of serial position, $F(7, 217) = 23.60$, $MSE = 562.38$, $p < .001$ (unaware: $F[7, 140] = 10.96$, $MSE = 603.79$, $p < .001$); and a significant Auditory Condition × Serial Position interaction, $F(21, 651) = 2.42$, $MSE = 88.84$, $p < .001$ (nonsignificant for unaware participants: $F[21, 420] = 1.49$, $MSE = 89.52$, $p = .076$). Planned repeated contrasts showed that performance was poorer in the consonants condition compared with the quiet condition, $F(1, 31) = 31.81$, $MSE = 1{,}009.95$, $p < .001$ (unaware: $F[1, 20] = 32.34$, $MSE = 608.19$, $p < .001$). More important, there was no reliable difference between performance in the consonants and digits-congruent order conditions ($F < 1$ [unaware: $F < 1$]), whereas performance was reliably poorer in the digits-incongruent order condition than in the digits-congruent order condition, $F(1, 31) = 3.93$, $MSE = 538.11$, $p < .05$ (unaware: $F[1, 20] = 5.20$, $MSE = 561.13$, $p < .05$). A subsequent contrast confirmed that performance in the digits-incongruent order condition was also poorer than that in the consonants condition, $F(1, 31) = 12.38$, $MSE = 288.27$, $p < .01$ (unaware: $F[1, 20] = 4.54$, $MSE = 367.71$, $p < .05$).

Discussion

Experiment 1 confirmed the suggestion in the data of two previous experiments that presenting irrelevant items that are identical to to-be-remembered items causes more impairment than presenting unrelated irrelevant items (Jones & Macken, 1995, Experiment 1; Salamé & Baddeley, 1982, Experiment 5). However, critically, this was only true when the order of the items was different in the two sequences; the level of performance when the order of irrelevant identical items was largely congruent with that of the to-be-remembered list did not differ from performance with unrelated irrelevant items (consonants). In short, this effect is driven by the particular order of the irrelevant items, not by their individual lexical identities or the individual phonemes they comprise.

The fact that the level of performance was comparable in the digits-congruent and consonants conditions provides some empirical corroboration for the notion that this order-incongruence effect was not driven by a facilitation of recall by virtue of explicit awareness of the order congruence in the digits-congruent order condition. Moreover, the observation also militates against the possibility that the difference between the digits-incongruent and digits-congruent order conditions was caused by some implicit positive priming process (e.g., Schacter, 1987) operating in the digits-congruent order condition due to the compatibility in the order of the irrelevant and relevant sequences in this condition. If either explicit or implicit knowledge of order compatibility had been acquired, it is reasonable to expect that performance would have been better in the digits-congruent order condition than in the consonants condition.

The results of Experiment 1 serve to further undermine the strong hypothesis that the primary determinant of the irrelevant sound effect is interference between the content of the individual elements making up the relevant and irrelevant sequences.[1] They also go against the weaker hypothesis that interference at the level of the individual elements in the sequence may have the capacity to exacerbate the irrelevant sound effect. Of course, in one sense, the order-incongruence effect is indeed driven by the particular content of the irrelevant sequence. However, crucially, the point that serves to pull the effect out of the reach of any classical interference-by-content explanation is that this content is information that is solely an emergent property of the process of placing the irrelevant items in a particular (incongruent) order. In other words, independent of the preattentive seriation process, the content of the individual elements in the irrelevant sequence is impotent in terms of disrupting serial recall.

The findings are also incompatible with the habituation-of-the-OR approach (Cowan, 1995), on the basis of which no difference between identical and unrelated conditions would have been expected let alone a difference between congruent and incongruent conditions. The feature model can accommodate the results, but only by virtue of its "attentional component," which, as noted earlier, is in need of greater specification before it can be used to predict particular outcomes.

In contrast, the order-incongruence effect may be explicable within an interference-by-process approach. When, as in the digits-order incongruent condition, the order cues are generated by, and therefore associated with, acoustic transitions (e.g., "three"–"seven") that are directly incompatible with those in the to-be-remembered sequence (e.g., *3–1*), there is a clash of seriation processes at a very specific level of the rehearsal process—namely, at the level at which the particular articulatory transitions needed to rehearse the items are to be specified. Given the novelty of this additional order-incongruence effect, in Experiment 2, we sought to replicate it but also included conditions that would allow us to further tease apart the interference-by-process account from the interference-by-content and habituation approaches to both the classical irrelevant sound effect and the present order-incongruence effect.

Experiment 2

As noted earlier, the weight of evidence suggests that so long as there are acoustic changes between successive elements in the irrelevant sequence (e.g., "five," "two," "five," "two," "five," "two" . . .), the changing-state effect will obtain, and increasing the number of novel tokens in the sequence (e.g., "five," "two," "eight," "five," "two," "eight" . . .) will not reliably augment the degree of disruption (Tremblay & Jones, 1998; but see Campbell, Beaman, & Berry, 2002). This finding suggests that the classical changing-state effect is reliant on the mere presence and salience of order cues between adjacent items regardless of the particular content of the items being linked by these order cues. However, the order-incongruence effect established in Experiment 1 seems indeed to be reliant on the presence of particular acoustic transitions between particular items. In light of this, we might expect that when the irrelevant and to-be-remembered items are identical, a *token set size* effect should be evident, but critically, only when increasing the token set size also means increasing the number of incongruent transitions. For example, a condition in which there are seven incongruent transitions (e.g., the digits-incongruent order condition in Experiment 1) should be more disruptive than one having, say, just two incongruent transitions.

In Experiment 2, therefore, we incorporated five auditory conditions (see Figure 3): (a) a *2-consonants* condition (in this case, two consonants were chosen randomly from the set of eight and repeated [e.g., "b, q, b, q, b, q, b, q"]), (b) an *8-consonants* condition (identical to the consonants condition in Experiment 1), (c) a *2-digits-incongruent order* condition (in this case, the irrelevant sequence consisted of the repetition of just two transitions [e.g., "four"–"seven" and "seven"–"four"] not appearing in the concurrent to-be-remembered eight-digit list (i.e., "four, seven, four, seven, four, seven, four, seven"), (d) an *8-digits-congruent order* condition (identical to the digits-congruent order condition in Experiment 1), and (e) an *8-digits-incongruent order* condition (identical to the digits-incongruent order condition in Experiment 1). A quiet condition was not included on this occasion so as to keep the duration of the experiment, which was highly cognitively demanding, within reasonable limits for the participants. Given that a strong irrelevant sound effect (i.e., poorer performance with irrelevant sound compared with quiet) had already been demonstrated in Experiment 1 using two of the same conditions included in this experiment, and given the general robustness of the irrelevant sound effect, we felt it unnecessary to replicate it again in Experiment 2.

Turning to the predictions for Experiment 2, on the basis of the interference-by-process account, we would predict that a token set size effect should only obtain when increasing the number of novel tokens means also introducing a greater number of incongruent transitions. Thus, there should be no difference between performance in the 2-consonants, 8-consonants, and 8-digits-congruent order conditions. However, performance should indeed be depressed in the 8-digits-incongruent order condition compared with the 2-digits-incongruent order condition as well as with the remaining three conditions. Moreover, there may be a sufficient degree of order incongruence in the 2-digits-incongruent order condition to produce poorer performance in this condition than in the 2-consonants, 8-consonants, and 8-digits-congruent order conditions. In sum, the interference-by-process account would predict the following outcome (where > represents *better recall than*): 8 consonants = 2 consonants = 8-digits-congruent order > 2-digits-incongruent order > 8-digits-incongruent order.

In contrast, the phonological-confusion account (Salamé & Baddeley, 1982) would predict that the more items the relevant and irrelevant sequences have in common, the greater will be the impairment to recall due to the greater degree of overlap between

[1] In the case of the phonological-confusion account (Salamé & Baddeley, 1982), the *elements* we refer to here would correspond to phonemes. However, proponents of the feature model (e.g., Nairne, 1990; Neath, 2000) have not as yet stated what a "feature" corresponds to in their model.

To-be-remembered items (visual): **5 1 7 3 8 4 6 2**

Auditory condition:

1. 2-consonants: **j h j h j h j h**
2. 8-consonants: **b h j k l m q s**
3. 2-digits: **4 7 4 7 4 7 4 7**
4. 8-digits-congruent: **6 2 5 1 7 3 8 4**
5. 8-digits-incongruent: **7 4 1 5 3 2 8 6**

Figure 3. A schematic illustration of how the five auditory conditions in Experiment 2 were generated. Note that the particular order of the items (and the particular items in the 2-digits and 2-consonants condition) as they appear in this figure are just possible examples of sequences that could have been presented in the experiment.

the individual phonemes in each sequence. Thus, performance should be better in the 2-digits-incongruent order condition than in either the 8-digits-incongruent order condition or the 8-digits-congruent order condition, between which there should be no difference. Moreover, as pointed out in the context of Experiment 1, the order of the eight irrelevant digits should make no difference; thus, performance should not differ between the 8-digits-incongruent and 8-digits-congruent order conditions. It is also possible that the 8-consonants condition should produce poorer performance than the 2-consonants condition because there is a greater likelihood of phonological overlap and, therefore, phonological confusion when the irrelevant sequence contains a greater number of different phonemes. It is unclear, however, whether the 2-digits-incongruent order condition would be expected to be more disruptive than the 8-consonants condition. This is because although there would be some cases of "perfect" phonological overlap in the 2-digits-incongruent order condition, there would be a greater number of different phonemes in the 8-consonants condition, and thus, the overall propensity for phonological confusion may be comparable in the two conditions. In sum, the phonological-confusion account would appear to predict the following outcome: 2 consonants > 8 consonants = (?) 2-digits-incongruent order > 8-digits-incongruent order = 8-digits-congruent order.

As noted earlier, if the feature model's feature-adoption mechanism is considered in isolation (i.e., without the "attentional parameter"), the model does not predict greater disruption from identical items (digits) than from unrelated items (consonants). Neither does it necessarily predict a basic token set size effect. This is because even when the irrelevant sequence is made up of just two repeating tokens, each token may coincide temporally with the presentation or rehearsal of a to-be-remembered item that has modality-independent features that differ in value. That is, the susceptibility of the to-be-remembered items to the corruptive influence of feature adoption is not necessarily decreased by having fewer novel tokens in the irrelevant sequence. In short, solely on the basis of the feature-adoption process, the feature model would not predict any differences between the five conditions in Experiment 2. However, it is possible that the feature model could accommodate and simulate a variety of outcomes by adjusting its "attentional parameter."

In contrast, the habituation-of-the-OR account offers a clear-cut prediction (Cowan, 1995). On this account, an OR (e.g., Sokolov, 1963) is triggered to the extent that a stimulus mismatches (i.e., is novel in relation to) a *neural model*: a mental description of recently encountered stimuli. Correspondingly, habituation occurs to the extent that the irrelevant sequence lacks acoustic novelty, hence accounting for why a sequence with one repeating item is far less disruptive than a sequence with changing items (e.g., Jones, Madden, & Miles, 1992). Therefore, this account predicts strongly that an irrelevant sequence in which all of the items are novel (eight consonants or digits) should be more disruptive than sequences with far fewer novel tokens (two consonants or digits). However, to the best of our knowledge, no theorist has ever claimed, on this account, that the relationship between the irrelevant and relevant items is an important factor. Thus, there are no grounds for expecting the identity of the irrelevant items to make a difference; that is, although the number of novel tokens should dictate the level of disruption, digits should be no more disruptive than consonants, irrespective of whether the order of the irrelevant digits is congruent or incongruent with the order of the to-be-remembered digits. In sum, the depletion-of-attentional-resources approach—including the way it is embodied in the feature model (through its use of an "attentional component")—predicts the following outcome: 2 consonants = 2 digits > 8 consonants = 8-digits-incongruent order = 8-digits-congruent order.

Method

Participants

Thirty psychology students at Cardiff University took part in the experiment in return for course credit. All were native English speakers and had normal hearing and normal or corrected-to-normal vision. None had participated in Experiment 1.

Apparatus and Materials

These were the same as in Experiment 1.

Design

As in Experiment 1, two factors were incorporated in a repeated measures design: auditory condition (five levels: 2 consonants, 8 consonants, 8-digits-congruent order, 2-digits-incongruent order, and 8-digits-incongruent order) and serial position (eight levels). There were 17 trials per auditory condition, making 85 trials in all. The order in which the conditions were presented was determined pseudorandomly, with the constraints that each condition was presented once every 5 trials and that there were no immediate repeats of any one condition.

Procedure

The procedure was the same as in Experiment 1—including the postexperiment "awareness"-questions procedure—except that the experiment lasted 50 min.

Results

Figure 4 shows the percentages of correctly recalled items in each of the five auditory conditions. On the basis of this figure, it

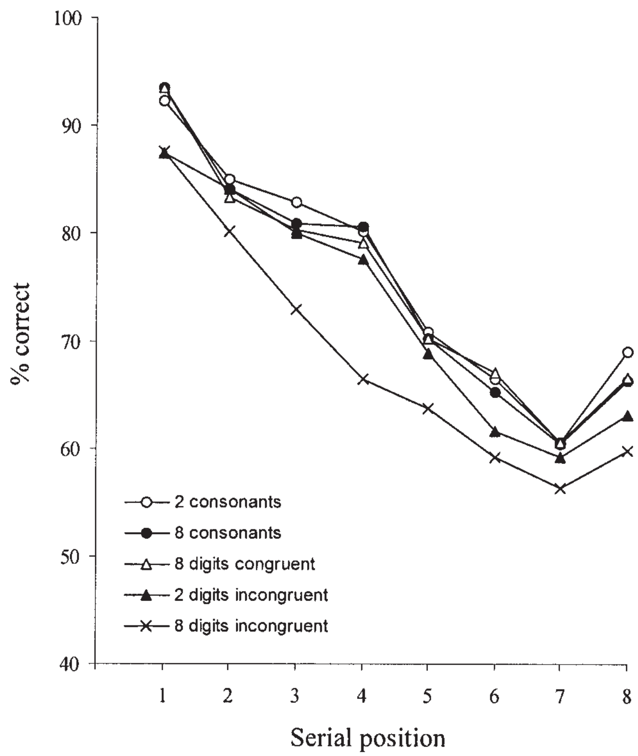

Figure 4. Mean percentages of items correctly recalled in the 2-consonants, 8-consonants, 8-digits-congruent order, 2-digits-incongruent order, and 8-digits-incongruent order conditions in Experiment 2.

is clear that performance in the 8-digits-incongruent order condition was markedly depressed compared with all other conditions. Moreover, there appears also to have been some decrement in performance in the 2-digits-incongruent order condition compared with the remaining three conditions, between which there were little if any differences. In short, the pattern of results conforms to that predicted on the basis of the interference-by-process account: 8 consonants = 2 consonants = 8-digits-congruent order > 2-digits-incongruent order > 8-digits-incongruent order. As with Experiment 1, the pattern of results was the same for the 23 participants who were categorized as "unaware" of the congruent-versus-incongruent manipulation as it was for all 30 participants.

A 5 (auditory condition) × 8 (serial position) repeated measures ANOVA revealed a main effect of auditory condition, $F(4, 116) = 9.85$, $MSE = 6.88$, $p < .001$ (unaware: $F[4, 88] = 7.54$, $MSE = 6.75$, $p < .001$); a main effect of serial position, $F(7, 203) = 38.00$, $MSE = 13.56$, $p < .001$ (unaware: $F[7, 154] = 25.23$, $MSE = 12.35$, $p < .001$); and no Auditory Condition × Serial Position interaction, $F(28, 812) = 1.27$, $MSE = 1.97$, $p > .05$ (unaware: $F[28, 616] = 1.23$, $MSE = 1.83$, $p > .05$).

Least significant difference post hoc analyses showed that performance in the 8-digits-incongruent order condition was significantly poorer than in any of the other four conditions ($p < .001$ in each case for all 30 participants; $p < .001$ in each case for the 23 unaware participants, except for the comparison between 8-digits-incongruent order and 2-digits-incongruent order, $p < .05$). Moreover, there was indeed a small but reliable decrement in performance in the 2-digits-incongruent order condition compared with the 2-consonants, 8-consonants, and 8-digits-congruent order conditions ($p < .05$ in each case, both with all 30 participants and with the 23 unaware participants). No other comparisons were significant.

Discussion

Experiment 2 yielded three findings of note. First, the order-incongruence effect observed in Experiment 1 was replicated; irrelevant digits disrupted the serial recall of the same set of digits to a greater extent than did irrelevant consonants, but only when the order of irrelevant digits was incongruent with the order of the to-be-remembered items. Second, there was no indication of a basic token set size effect; simply having eight different tokens in the irrelevant sequence (8-digits-congruent order and 8-consonants conditions) caused no more disruption than having two different irrelevant tokens (2-digits-incongruent and 2-consonants conditions). The absence of a basic token set size effect casts doubt on the one previous experiment in which such an effect was found (Campbell et al., 2002, Experiment 3b) and buttresses the claim that the classical changing-state effect is driven by acoustic changes between immediately adjacent items (Tremblay & Jones, 1998).

Third, although there was no basic token set size effect, there was clear evidence of an *incongruent-transitions set-size effect*; when adding further tokens from the same set as the to-be-remembered list introduced a greater number of transitions that were incongruent with those in the to-be-remembered sequence (i.e., the 8-digits-incongruent order condition compared with the 2-digits-incongruent order condition), performance was poorer. Even the presence of two incongruent transitions (2-digits-incongruent order condition) gave rise to an order-incongruence effect. That is, presenting an irrelevant sequence that exhibited two transitions that were incongruent with those in the to-be-remembered sequence not only caused more disruption than two consonants but, most notably, more disruption than conditions with eight tokens but in which there was no order incongruence (8-consonants and 8-digits-congruent order conditions). This provides compelling evidence that presenting irrelevant items that are identical to those in the to-be-remembered set is only more disruptive when their order conflicts with that required to perform the primary task; the effect has nothing to do with the content of, or number of tokens within, the irrelevant sequence per se.

It is worth noting also that the incongruent transitions set-size effect arose as the result of an increase in the degree of order incongruence, not a decrease in the degree of order congruence (because in neither the 2-digits-incongruent condition nor the 8-digits-incongruent order condition was there any order congruence). This buttresses the view that the poorer performance in the 8-digits-incongruent order condition compared with the 8-digits-congruent order condition was not driven by a facilitation of performance in the latter condition.

In terms of the predictions of the various approaches to the irrelevant sound effect, the results of Experiment 2 are most readily accommodated by an extension of the interference-by-process account of the irrelevant sound effect (Jones & Tremblay, 2000). At the same time, they cast further doubt on the phonological-confusion account (Salamé & Baddeley, 1982); can be accommodated by the feature model, but only by its appeal to an as-yet-underspecified "attentional component" (Neath, 2000); and directly refute a prediction gleaned from the habituation-of-the-OR account (Cowan, 1995).

General Discussion

To summarize, the results of the current experiments indicate that presenting irrelevant auditory items that are taken from the same lexical set of items that form the to-be-remembered set disrupts serial recall to a greater extent than does presenting different items (consonants), but only when the order of the identical irrelevant items is incongruent with that of the to-be-remembered items. Moreover, in Experiment 2, there was evidence that the additional disruption was a function of the number of incongruent transitions within the irrelevant digit sequence, not a function of the number of novel irrelevant tokens per se. Finally, the effect does not seem to be reliant on participants acquiring either explicit or implicit knowledge of the nominally irrelevant information in the digits-congruent conditions.

One concern is why Bridges and Jones (1996) failed to find more disruption when the irrelevant items were identical to the to-be-remembered set of items (digits 1–9) than when the irrelevant items were unrelated disyllabic words. One possibility is that disyllabic words would yield a greater number of order cues (given that there would be relatively sharp acoustic mismatches between syllables within each word), hence producing a greater classical changing-state effect than the digits 1–9, which may in turn have offset any order-incongruence effect (but see Salamé & Baddeley, 1982). Similarly, the unrelated words in Bridges and Jones's (1996) Experiment 5—"bed," "sap," "pick," "stop," "neck," "tip," "nut," "cat," and "duck"—may have also given rise to a greater classical changing-state effect, because each of these words has a bilabial (/p/), velar (/k/), or palatoalveolar (/t/, /d/) offset, hence they are likely to have exhibited sharper transitions in energy at word boundaries and, in turn, more salient order information than the digits 1–9, which all (except for "eight") have either a vowel offset or an alveolar offset (/n/, /s/, /v/).

The present order-incongruence effect is incompatible with any approach to the irrelevant sound effect that relies solely on interference by content. Neither the phonological-confusion account nor the feature model (without an additional "attentional component"; see below) can easily explain the order-incongruence effect. This is because this additive effect is clearly not due to the content of the *individual* elements in the irrelevant sequence becoming confused with or corrupting the representations of the *individual* elements in the to-be-remembered sequence. By extension, the irrelevant sound effect and the order-incongruence effect undermine the more general notion that interference between irrelevant and relevant stimuli occurs when some "limited-capacity" processing structure dealing with postcategorical representations becomes overloaded (e.g., Broadbent, 1958).

The notion that sound draws "attentional resources" away from the primary task by virtue of an attentional OR (Cowan, 1995; Elliott, 2002) is also further undermined by the present results. This account already faces a number of difficulties too numerous to list here (but see Tremblay & Jones, 1998), but to these we can now add that it fails to explain why irrelevant digits disrupt the serial recall of digits more than do unrelated items, particularly given that this is only the case when the digits in the two sequences are presented in incongruent orders. Moreover, the fact that in Experiment 2 it was found that irrelevant sequences in which every item was novel (the 8-consonants and 8-digits-congruent conditions) produced no more disruption than a sequence in which there were only two novel items (two consonants)—and actually produced less disruption if those two novel items formed two incongruent transitions (2-digits-incongruent condition)—seems highly problematic for this view.

Generally, the results give little succor to accounts embodying an attention-as-resource construct, either as a sole explanatory construct or in conjunction with feature adoption. The key difficulty with this construct has already been noted by Jones and Tremblay (2000) in relation to its use in the feature model: "The attentional factor has no clear empirical referent, except the depression in performance that is the prior sign of its action" (p. 556). Thus, the ability to simulate an effect by adjusting a free parameter is of little theoretical value unless the psychological construct to which the parameter corresponds has been clearly specified and has an independent empirical referent. More generally, the fact that the depletion-of-attentional-resources approach (Cowan, 1995; Elliott, 2002; Neath, 2000) does not provide a satisfactory account of the present results may be symptomatic of the inherent circularity of the notion that attention can be conceptualized as a limited processing resource or set of resources (for an extensive critique, see Neumann, 1996).

The order-incongruence effect seems most readily accommodated within the interference-by-process approach to the irrelevant sound effect (e.g., Jones & Tremblay, 2000). At the core of this account is the assumption that the process of rehearsal—on which overt serial recall is ultimately based (see Macken & Jones, 2003)—involves the deliberate cyclical retracing of an episodic record containing a set of order cues representing the to-be-remembered sequence (or the *episodic trajectory*; see Jones et al., 1996). When the presence of irrelevant sound yields strong order cues—as in the case of a changing-state sequence—these irrelevant order cues must be inhibited so as to avoid the derailment of the process of retracing the correct episodic trajectory (for evidence suggesting that preattentively generated auditory order cues are inhibited in this setting, see Hughes & Jones, 2003b). The classical changing-state irrelevant sound effect may therefore be construed as the residual cost of having to inhibit irrelevant order cues that are congruent with the general class of action demanded by the primary task—namely, seriation (irrespective of the particular items to be seriated)—but incongruent with the requirement to seriate the to-be-remembered items.

The order-incongruence effect may be understood as the result of a conflict between irrelevant and relevant episodic trajectories at a more specific level of the process of seriating the to-be-remembered items. If the to-be-remembered sequence contains the subsequence *4*, *6*, *1*, *3*, for example, then in an order-incongruent condition, the irrelevant order cues would represent, or be associated with, transitions (e.g., "four"–"three"–"one"–"six") that are highly congruent with the kind of articulatory transitions that need to be made to serially rehearse the to-be-remembered material (i.e., transitions between digits) but at the same time would be incongruent with the particular transitions required for correct serial recall (i.e., "four"–"six"–"one"–"three"). Thus, the order-incongruence effect may arise because the irrelevant information is "congruent-and-yet-incongruent" with the seriation process demanded by the primary task at a more specific level than is the case with irrelevant information that is unrelated to the to-be-remembered items (e.g., irrelevant tones [Jones & Macken, 1993] or consonants, as used in the present study)—namely, at the level of specifying the particular articulatory transitions that are to be made between to-be-remembered items. In turn, it seems plausible to argue that such order cues would require more inhibition than neutral or congruent order cues (e.g., such as in the consonants and digits-congruent order conditions in the present study, respectively), hence accounting for the additional degree of residual interference. However, it might be asked why a numerical trend for greater disruption has often been observed when the individual phonemes but not the entire items in the irrelevant and relevant sequence have been identical or similar (Bridges & Jones, 1996; Jones & Macken, 1995; LeCompte & Shaibe, 1997; Salamé & Baddeley, 1982). One possibility is that the incongruent transitions between the phonemes in the irrelevant and relevant sequences in an *identical-(or similar)-phonemes* condition might have resulted in a weak and not always reliable order-incongruence effect. However, further research is clearly needed to address precisely what aspects of the irrelevant items drive the order-incongruence effect.

The notion that both the irrelevant sound effect and the additional order-incongruence effect are dependent on the information extracted from the sound (i.e., order cues) being "congruent and yet incongruent" with the action demanded by the primary task (i.e., serial articulatory rehearsal in the present context) closely allies the interference-by-process account to a broader *selection-for-action* approach to attentional selectivity and interference between competing stimuli (e.g., Allport, 1989; Neumann, 1987, 1989, 1996; see also Anderson, 2003). On this view, interference from task-irrelevant information is not the result of the overloading of some discrete limited-capacity processing structure or short-term store (e.g., Broadbent, 1958) or of the depletion of some limited attentional resource (e.g., Kahneman, 1973; Wickens, 1984). Rather, interference is the inevitable side effect of the operation of specific mechanisms (e.g., inhibition; see Houghton & Tipper, 1994) that function to prevent irrelevant information that is congruent with the class of action—but incongruent with the specific action—demanded by the primary task from actually assuming the control of action. Indeed, the same congruent-and-yet-incongruent hypothesis seems to hold also, at least broadly, in the context of Stroop and Stroop-like effects (for an overview, see MacLeod, 1991), Eriksen flanker effects (Eriksen & Eriksen, 1974), the effect of distractor objects in reach-and-grasp tasks (e.g., Tipper, Howard, & Jackson, 1997), the effect of information in the unattended channel in auditory shadowing tasks (Broadbent, 1958; Treisman, 1964; see Allport, 1989), and visual attentional capture or pop-out effects in visual search tasks (e.g., Folk, Remington, & Johnston, 1992), to name but a few examples. In conclusion, the present results support a view of attentional selectivity in which interference between task-irrelevant and task-relevant stimuli reflects the relatively small price to be paid for the operation of functionally healthy mechanisms that ensure that the currently task-relevant information assumes the control of goal-directed action.

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