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The irrelevant-speech effect and children: Theoretical implications of developmental change

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The irrelevant-speech effect refers to the finding of impaired recall performance in the presence of irrelevant auditory stimuli. Two broad classes of theories exist for the effect, both allowing automatic entry of the distracting sounds into the processing system but differing in how attention is involved. As one source of evidence in the discussion of existing theories of the irrelevant-speech effect, the performance of children and adults on a visual serial recall task with irrelevant sounds (speech and tones) was examined. The magnitude of the effects of irrelevant sounds on performance decreased with age. The developmental differences were marked in the conditions with the greatest need for attentional control (words and especially changing words). The findings were interpreted with respect to current models of memory. Theories of the irrelevant-speech effect that include a role for attentional control were better suited to handle the results than those without a specified role for attention.

Colle and Welsh (1976) examined the effects of irrelevant-speech sounds on a serial recall task with visually presented items and found that speech impaired performance on the recall task. This finding has been referred to as both the *irrelevant-speech effect* (Salamé & Baddeley, 1982) and the *irrelevant-sound effect* (ISE; Jones & Macken, 1993), inasmuch as nonspeech sounds also cause interference. The ISE is a well-established effect in the adult cognitive literature (for a recent review see Neath, 2000, and the replies by Baddeley, 2000b, and Jones & Tremblay, 2000), but has not been used in the childhood developmental study of the effects of irrelevant sounds on performance.

The first goal of the present study was to assess children's performance on a serial recall task in the presence of irrelevant auditory information and to investigate developmental change in this task. The second goal of this study was to examine current theories of irrelevant-sound effects within the context of developmental change. Understanding more about developmental change in the effects of irrelevant sounds can help to inform theories of the effects of irrelevant sounds on performance. These two goals will be discussed more fully in turn.

With development, children's ability to remember item lists, a measure referred to as memory span (Chi, 1977), improves. Although there are multiple causes for the increases in span, developmental improvements in both the encoding and retrieval of memory for serial order information are thought to be involved (McCormack, Brown, & Vousden, 2000). Also, rehearsal increases with development, and rehearsal improves memory performance (Flavell, Beach, & Chinsky, 1966). Children begin to rehearse in a more cumulative fashion with increasing age (Ornstein, Naus, & Liberty, 1975).

Another relevant aspect of developmental change is that children differ from adults in attentional control (e.g., in directed forgetting in a recall task, Harnishfeger & Pope, 1996; in selective listening, Doyle, 1973, and Lane & Pearson, 1982; and in inhibition, Dempster, 1993, Hale, Bronik, & Fry, 1997, and Tipper, Bourque, Anderson, & Brehaut, 1989). Given these known developmental changes, studying participants of differing ages is a likely way to extend the empirical findings and theoretical understanding of the ISE. Because of their poorer attentional control abilities, children may perform more poorly than adults in the presence of irrelevant sounds.

Empirical study of developmental change in the effects of irrelevant sounds on performance presents an opportunity to learn more about the nature of disruption by distracting sounds. Several theories of the effects of irrelevant sounds exist, and each has unique aspects that developmental findings can help to support or refute (Cowan, 1995; Jones, 1993; Neath, 2000; Salamé & Baddeley, 1982). An important element of the ISE is that instructing participants not to attend to the irrelevant material is insufficient to avoid the disruptive effects (Boyle & Coltheart, 1996; Salamé & Baddeley, 1982). It is presumed that the sounds enter the processing system outside of the participant's control, thus bringing into question the exact nature of such disruption.

Most theories of the ISE can be grouped into two broad classes—automatic access of the irrelevant sounds with-

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out a specified role for attention, and theories that include a role for attention (for an alternative classification of these theories on the basis of process vs. content interference, see Jones & Tremblay, 2000). These theories will be discussed in the following two sections, including predictions of developmental change within the context of each theory.

Automatic-Access Theories Without a Specified Role for Attention

Salamé and Baddeley (1982) examined the effects of irrelevant sounds on the serial recall performance of adults, using visually presented items. Phonological similarity of the relevant and irrelevant items was found to increase the amount of disruption relative to phonologically dissimilar items. Salamé and Baddeley (1982) concluded that the speech sounds gain automatic entry into the auditory store of memory (i.e., phonological store) where the visual to-be-remembered items also enter, through subvocal rehearsal. With representations of both the irrelevant auditory and the visual items in the phonological store, confusion among these items becomes more likely, and recall performance decreases.

Salamé and Baddeley's (1982) findings were incorporated into Baddeley's working memory model (WM; Baddeley, 1986). The automatic-access assumption of the WM model predicts that the sounds would enter a child's processing system in the same manner as an adult's. However, the WM model acknowledges developmental changes in processing, especially of speech sounds in the phonological storage component of the memory system (Baddeley & Hitch, 2000). Evidence suggests that children do not reliably recode visual materials into verbal codes until around the age of 8 or 9 years (Baddeley & Hitch, 2000). The result could be *smaller* disruptive effects of irrelevant sounds in young children who are not using the phonological store to recode the visually presented items for rehearsal. Instead, the children may be relying on visual codes in the visual–spatial sketchpad (Baddeley, 1986) or an episodic buffer (Baddeley, 2000a) to recall the visual items. If young children are not recoding the visual items to a phonological form, then the conflict between items cannot occur in the phonological store.

Following the work of Salamé and Baddeley (1982), evidence that varied speech or nonspeech sounds were more disruptive to memory performance than sounds that remained the same (Jones, Madden, & Miles, 1992) led to the emergence of another model of the effects of irrelevant sounds on performance, the object-oriented episodic record model (O-OER; Jones, Macken, & Murray, 1993). Two central tenets of the O-OER are the *changing-state hypothesis* and the *equipotentiality hypothesis*. The first hypothesis states that auditory distractors that change in state, or vary over time (Jones et al., 1993), disrupt performance more than items that remain the same. The second states that if speech and nonspeech sounds are equated for state changes, then speech and nonspeech sounds are functionally equivalent in the amounts of disruption caused (Jones & Macken, 1993).

Building upon these two hypotheses, the O-OER model states that the ISE is the result of conflict between two separate processes of seriation. When items are presented, either through the auditory or the visual modality, they enter the processing system as objects on a metaphorical blackboard of memory. Serial order information of these objects is represented as links, or pointers, between objects. The order information of the visual, to-be-remembered items is maintained by rehearsal, whereas the order information of the auditory irrelevant items is encoded automatically. Through the automatic access of auditory stimuli to the processing system, the pointers relevant to the visually presented items conflict with the serial order information for the auditory items. When the participant recalls the items, confusion among the pointers for the irrelevant items and the test items results. Disruption occurs because of the similarity of process between the order information in the two sets of stimuli (Jones & Tremblay, 2000). This model of the ISE has received support from a range of findings (see Jones & Tremblay, 2000).

Jones's O-OER model has not made precise predictions regarding developmental change. However, the O-OER emphasizes the importance of the rehearsal of the to-be-remembered items for the formation of links between objects (Macken, Mosdell, & Jones, 1999; Miles, Jones, & Madden, 1991). Because of known developmental changes in rehearsal (Flavell et al., 1966; Ornstein et al., 1975), one might predict that the youngest children would show *smaller* disruptive effects of irrelevant sounds relative to adults. The conflict between the two types of order information is central to the disruption by irrelevant sounds. Jones and Macken (1995) described the effect in the following manner: "Full-blooded disruptive effects of irrelevant speech are the result of the conflict of two sets of order cues . . . one from deliberate rehearsal of a list and the other from preattentive organization of the heard material. The results of our experiments suggest that weakening of order cues in either set diminishes the degree of disruption" (p. 114). Thus, children who are not systematically rehearsing the visual items would not have strong cues for the serial order of these to-be-remembered items, which would lead to a smaller disruptive effect of the irrelevant sounds on children's memory performance. However, this is only one interpretation of developmental change within the context of the O-OER, since the model has not been made specific in this regard.

Theories Including a Role for Attention

In light of some mixed support of the effects of phonological similarity and the ISE (Jones & Macken, 1995), as well as other findings (Jones & Macken, 1993), Jones had proposed the changing-state hypothesis as an alternative to Salamé and Baddeley's explanation. However, Cowan (1995) pointed out that an explanation of *attentional recruitment* away from the visual items by the changing sounds was another alternative. The key difference between Cowan's framework and the other theories of the ISE lies in the disruption of performance by irrelevant sounds; the sounds recruit attention away from the relevant items to be recalled. Visually presented items in the serial recall task are kept active in memory using the focus of attention and rehearsal processes. The auditory items can recruit attention, interfering with rehearsal processes and resulting in poorer recall of the visual items.

Another element of this framework is that habituation of the attentional orienting response (Sokolov, 1963) is described as a possible mechanism of selective attention (Cowan, 1995). The orienting response is an attentional response to changes in the environment. To summarize briefly, a mental model of distracting stimuli is formed with repeated presentations of the stimuli. Each new stimulus is compared with the mental model, and the orienting response results when a discrepancy is detected. Changes in sounds produce discrepancies from the existing mental model of the sounds, interfering more than sounds without changes. Support for the habituation hypothesis has been found in a variety of tasks (Elliott & Cowan, 2001; Lorch, Anderson, & Well, 1984; Tipper et al., 1989; Waters, McDonald, & Koresko, 1977). However, some studies have not yielded evidence of habituation to irrelevant speech (Hellbrück, Kuwano, & Namba, 1996; Tremblay & Jones, 1998), and the role of attention in the ISE remains controversial.

Recently, data relevant to the habituation hypothesis were presented in a study of habituation of the orienting response in a color-naming task (Elliott & Cowan, 2001). Although Elliott and Cowan found that reaction times improved when participants heard repetitions of the distracting items, interference from the auditory distractors was never completely eliminated. This suggests that habituation of the orienting response can aid responding, but that it does not prevent the auditory distractors from entering the processing system.

This interpretation is applicable to the task situations common for irrelevant-sound tasks, in which a small set of auditory stimuli are presented repeatedly. In the presence of repeated distractors, habituation of the orienting response will help to suppress the auditory items. However, in the presence of changing items where there is less habituation of orienting, individuals who can apply their attentional control to tag the visual items as relevant will have improved recall performance relative to those who cannot do this as successfully.

Cowan's (1995) memory framework has been applied to developmental change, and that change is described as the result of increases in the capacity of items that can be maintained in the focus of attention, increases in the search rate at which activated items can be brought into the focus of attention, and decreases in the rate at which items decay from activation (Cowan, Saults, & Elliott, 2002). Changes in these areas of the memory system affect recall because it is based on the information that is present in the focus of attention. Developmental changes in the efficiency of attention have been described as well (Cowan, 1997). With these developmental changes in memory and the efficiency of attention, this model predicts developmental changes in the disruption by irrelevant sounds. Children would be expected to show *larger* effects of irrelevant sounds because of inferior control of attention relative to adults. The disruption of attention by the changing sounds could be more detrimental to the rehearsal efforts of the children, for whom rehearsal requires more mental effort than in adults (Bjorklund & Douglas, 1997; Guttentag, 1984). Also, inferior control of attention could operate by making suppression of the irrelevant items (or the ability to tag the relevant items) more difficult, leading to a larger number of errors in children's recall.

Using a slightly different approach, Neath has introduced a mathematical model of the ISE based on the feature model (Nairne, 1990; Neath & Nairne, 1995). One advantage of this model over previous explanations of the ISE is its ability to describe patterns of serial order errors. This model describes memory traces as vectors of features, and recall occurs through a process of matching memory traces. The irrelevant sounds interfere with the integrity of the memory traces with similar features by overwriting those features, which results in a lower probability of a correct match, thus causing the decrement in serial recall performance. An *attentional parameter* is included in the model and is changed to reflect the amounts of processing that are needed for task demands. For example, some tasks require a greater amount of general attentional resources than others, such as generating sounds as opposed to just hearing sounds. Changing the attentional parameter allows for predictions of the amount of disruption that will be caused by differing task demands.

Using this model, Neath was able to successfully simulate several of the empirical findings from the ISE literature. However, he has not explicitly modeled nonspeech sounds. This is regarded as a major weakness for the feature model (Jones & Tremblay, 2000). Neath has suggested that the ISE might be comparable to a dual-task situation (i.e., remembering the relevant items and ignoring the irrelevant). Thus, in addition to overwriting features when speech sounds are presented, ignoring sounds is a task in itself, regardless of whether the sounds are speech or nonspeech (Neath, 2000).

Specific developmental simulations of the feature model (Neath, 2000) have not been performed with the ISE. The model could predict developmental change by adjusting the attentional parameter. The amount of attention that is available during task performance is important for determining the amount of disruption that can be caused by distracting stimuli. If the parameter were set to different values for children and adults, which is reasonable considering the developmental change in attentional resources (Cowan, Nugent, Elliott, Ponomarev, & Saults, 1999), *larger* detrimental effects of irrelevant sounds would be expected in children. Children would have less attention available, meaning a lower amount of available resources, relative to adults. For example, the changing-state effect is modeled by changing the attentional parameter on the basis of the logic that a repeated item is easier to ignore than are changing items. When an item is easier to ignore, less of the available attentional resources are diverted from the primary task. Adults would generally have greater attentional resources available, thus making the irrelevant items easier for adults than for children to ignore.

The Present Study

Most studies of the ISE on serial recall have used one list length, typically eight or nine items (Jones & Macken, 1993; LeCompte, 1995). However, detrimental effects of irrelevant sounds on recall have been found in adult participants with lists of five to eight letters (Salamé & Baddeley, 1986). For this task to be suitable for both children and adults, list lengths relative to a participant's span and below, rather than a fixed list length, were used. Span was operationally defined as the highest list length at which at least one list was correctly recalled. Span was first assessed using a visual serial recall task, and then the list lengths of the serial recall task with irrelevant sounds were based on the span assessment. This span-matching procedure was used to equate the level of difficulty of the serial recall task across age groups.

On the basis of the adult literature, changing- and steady-state sounds were included to determine whether children would show the same patterns of responding as adults (i.e., the changing-state effect). Also, increasing knowledge of speech with development is an important factor, and the inclusion of both speech and tone irrelevant-sound conditions in this developmental study allowed an additional source of information for investigating the theories of the ISE.

In summary, detrimental effects of irrelevant sounds have been demonstrated in adults using serial recall tasks. Theories of the effects of irrelevant sounds have not explicitly described developmental change in these effects, but the theories lead to differing predictions. The theories without a specified role for attention appear to lead to predictions of either no developmental change in this task or an increase in the magnitude of disruption with development. On the other hand, the theories with a specified role for attention predict a decrease in the magnitude of disruption with development. In an investigation of the theoretical predictions, this study explored developmental change in the effects of irrelevant sounds.

METHOD

Participants

Thirty-two participants from each of four age groups were used in the data analyses: second graders (M = 8 years, 3 months, SD = 5 months), third–fourth graders (M = 9 years, 6 months, SD = 6 months), fifth–sixth graders (M = 11 years, 8 months, SD = 7 months), and adults (M = 19 years, 0 months, SD = 2 years). Of a total of 131 participants, 3 were excluded from the data analyses. One child had poison ivy and could not perform most of the tasks due to general fidgeting, and 2 adults did not complete all of the tasks because of illness. All participants reported normal or corrected-to-normal vision, color vision, and hearing. The children were recruited from the Columbia Public School system and received $10 and a book for their participation. The adults were recruited from the Department of Psychology's participant pool and received credit in their psychology class.

Apparatus, Stimuli, and Procedure

Participants were tested one at a time in sound-attenuated booths, and the experimenter was with the participants at all times. The general procedure was for the participant to sit in front of the monitor and to type the responses using the number keypad of the computer keyboard. The programs were written using MEL2 (Micro Experimental Laboratories, Version 2.0; Schneider, 1988). The tasks were run in the following order: the visual span task, the serial recall task in the presence of irrelevant sounds, and then the second visual span task. These tasks were always administered as the first tasks within an experimental session that continued with some other tasks that the participants could not anticipate. These other tasks (an auditory span task, a color-naming task, and two working memory span tasks) will not be discussed further. The duration of the first three tasks (the visual span tasks and the irrelevant-speech task) was approximately 40 min. Children were rewarded with stickers after the completion of each task and were given several opportunities for breaks.

Visual span task. The stimuli in the visual serial recall tasks were presented in the center of the monitor one at a time and were presented in random order during practice trials and the test trials. The digits 1–9 were presented as the visual stimuli in the simple span task and in the irrelevant-sound task, at the rate of one per second. A computerized measure of the participant's memory span for visual items was taken. On each trial, printed lists of digits were presented and participants were asked to type responses using the number keypad in the order in which the numbers were presented. Span was defined as the highest list length at which the participant reproduced at least one list correctly. This allowed span to be recorded as an integer score by the computer program, which was then used to set the relative list lengths for the irrelevant-sound serial recall task. First, the participant received three practice trials of List Length 3. Then the span test presented three lists at each list length, with the range of three to nine items. Two visual span tests were administered, one before the irrelevant-sound serial recall task, and one afterward to obtain an estimate of test–retest reliability.

Serial recall with irrelevant sounds. The auditory stimuli for the irrelevant-sound task were presented one at a time in a male voice and consisted of words, tones, and silence. The changing-state word stimuli were randomly drawn from a pool of nine words: *red*, *blue*, *green*, *yellow*, *white*, *tall*, *big*, *short*, and *long*. The steady-state word condition consisted of the word *red* repeatedly presented. The words were matched in word frequency according to Carroll, Davies, and Richman (1971) and were selected because of the other tasks not reported here. However, even in the other tasks, participants were to ignore any irrelevant sounds at all times. Participants had no reason to suspect that the distracting sounds would ever be relevant to responding, and the participants were not aware of the exact nature of each task until immediately before performing the task.

The spoken stimuli were in the range of 210–500 msec and were digitized and combined with silence using a sound-editing program to create a one-item-per-second presentation rate. Sound onsets were simultaneous with the onset of the visual stimuli. All sounds were presented over TDH-39 earphones. Nine tones from a range of frequencies (266–608 Hz) were used, with a 10% difference between adjacent tones in the set. The changing-state tone condition consisted of a random selection from the pool of nine tones of different frequencies, and the steady-state tone was a 1000-Hz tone. The levels for each condition were selected for subjectively equal loudness and, as measured with a sound-level meter and accompanying earphone coupler, were as follows: silence, 45 dB(A); changing-state word, 72 dB(A); steady-state word, 72 dB(A); changing-state tone,

Table 1
Means and Standard Deviations of Visual Span for Each Age Group

		Cumulative		Maximum	
Age Group	Span Run	*M*	*SD*	*M*	*SD*
Second graders	1	4.3	0.79	5.0	0.80
	2	4.4	0.68	5.0	0.67
Third–fourth graders	1	4.9	0.78	5.4	0.98
	2	4.9	0.91	5.8	1.18
Fifth–sixth graders	1	5.6	0.78	6.4	0.94
	2	5.6	0.84	6.1	1.10
Adult	1	6.6	1.03	7.4	1.27
	2	6.8	1.22	7.4	1.31

71 dB(A); and steady-state tone, 68 dB(A). In any case, the degree of disruption by irrelevant sounds on serial recall has been shown to be independent of the intensity of the sounds (Ellermeier & Hellbrück, 1998; Tremblay & Jones, 1999).

The irrelevant-sound trials comprised lists presented at four list lengths (the participant's span as determined by the visual span procedure, span minus 1, span minus 2, and span minus 3). Five auditory conditions (changing-state words, steady-state words, changing-state tones, steady-state tones, and silence) were used, for a total of 20 trial types (5 auditory conditions $\times$ 4 list lengths). The participants saw a small fixation cross in the center of the screen for 750 msec, and then the visual stimuli were presented. The participants were instructed to ignore any sounds heard through the headphones and to concentrate on remembering the numbers. They were asked to type their recall of the numbers in order. The participants received one practice block of five trials, one of each auditory condition at list length span minus 3. The auditory conditions were quasi-randomly presented for a total of 65 trials, including the 5 practice trials. This total number of trials included three repetitions of each of the 20 trial types.

RESULTS

Maximum span values were recorded as the highest list length at which a participant answered at least one list correctly. This was done to provide an integer value for the computer program to set the relative list lengths in the serial recall task with irrelevant sounds. A more sensitive measure (cumulative span) was also calculated. This method involved beginning with the highest list length at which all lists were correctly recalled and then adding 0.33 for each additional list correctly recalled (Towse, Hitch, & Hutton, 1998).

Visual Span Task

Means for both methods of calculating span are reported in Table 1 for all age groups. The first and second span runs yielded very similar estimates of span. A one-way between-subjects analysis of variance (ANOVA) was conducted to examine developmental change in the span task, with cumulative span from the first span run as the dependent measure. Significant developmental improvements in span were found [$F(3,124) = 47.47$, $MS_e = 0.73$, $p < .001$]. A post hoc Newman–Keuls test indicated that all four age groups were significantly different from each other.

Serial Recall with Irrelevant Sounds

Proportions correct for serial recall performance in the presence of the five auditory conditions (silence, changing-state words and tones, and steady-state words and tones) at lists of span length were entered into a 5 $\times$ 4 ANOVA with the five auditory conditions as a within-subjects factor and age group as a between-subjects factor. This analysis resulted in significant main effects of auditory condition [$F(4,496) = 49.31$, $MS_e = 0.02$, $p < .001$] and age group [$F(3,124) = 5.03$, $MS_e = 0.14$, $p < .001$]. The interaction of these two factors was also significant [$F(12,496) = 2.83$, $MS_e = 0.02$, $p < .001$]. The means and standard errors are shown in Figure 1. The presence of

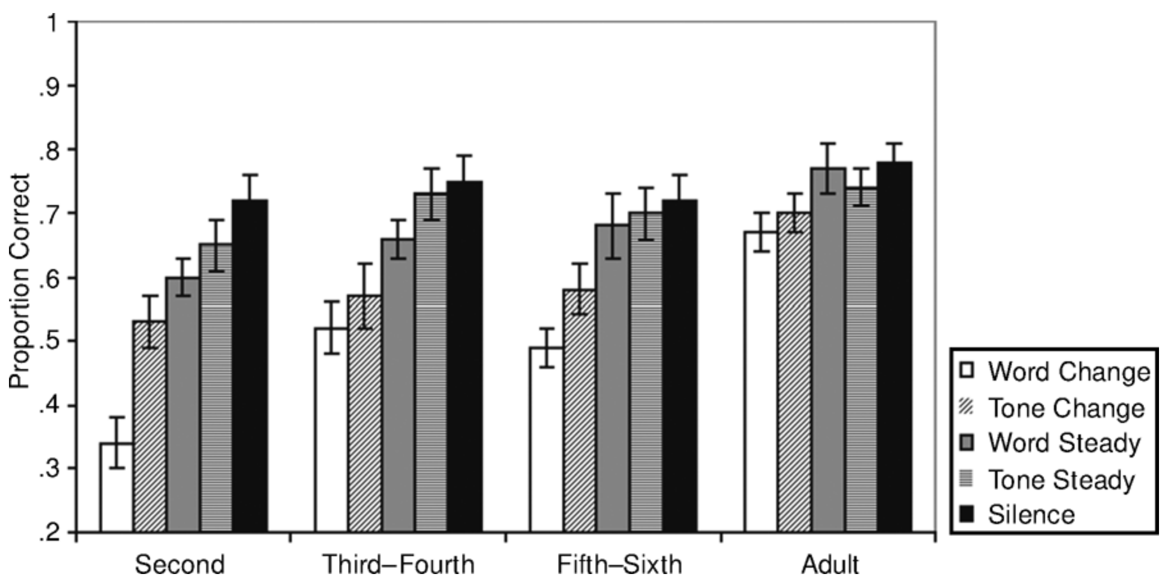

Figure 1. Age group means of the auditory conditions from the serial recall task, for lists of span length only. Errors bars represent standard error of the mean.

Table 2
Proportion Difference Scores for Each Age Group

Age Group	Proportion Difference	*SD*
Second	0.39	0.20
Third–fourth graders	0.24	0.26
Fifth–sixth graders	0.24	0.25
Adult	0.11	0.17

Note—Proportion difference scores were calculated by subtracting performance in the changing-state words condition from the silent condition for lists of span length.

sounds caused a decrease in recall performance, relative to silence, and performance was hurt most by the changing-state words. The youngest children showed the largest ISE, and it diminished with increasing age.

For an additional measure of developmental change, difference scores were calculated to compare performance in the most disruptive condition, the changing-state words condition, with performance in the silent condition for lists of span length. Clear developmental differences emerged: The youngest participants showed much larger difference scores than the adults (Table 2). This clearly illustrates that children are more affected by distracting sounds than are adults.

Another noteworthy element of Figure 1 is that performance in the silent condition for span-length lists was comparable for the participants. This indicates that the span-matching manipulation was successful. Thus, the age difference in performance that resulted in this irrelevant-sound task were not due to large differences in baseline levels of performance.

To examine more specifically both the effects of changing-state versus steady-state and words versus tones, the silent condition was excluded and the remaining four auditory conditions for lists of span length were analyzed in a 2 (state) × 2 (lexicality) × 4 (age group as a between-subjects factor) ANOVA. The main effects of state [$F(1,124) = 89.32$, $MS_e = 0.03$, $p < .001$], lexicality [$F(1,124) = 21.12$, $MS_e = 0.02$, $p < .001$], and age group [$F(3,124) = 6.02$, $MS_e = 6.02$, $MS_e = 0.12$, $p < .001$] were all significant. These main effects are consistent with extant findings, showing a changing-state effect (i.e., changing-state conditions, $M = 0.55$, were more disruptive than the steady-state conditions, $M = 0.69$), an effect of lexicality (i.e., words, $M = 0.59$, were more disruptive than tones, $M = 0.65$), and an effect of age (i.e., proportions correct increased with age). Additionally, all of the two-way interactions were significant: state × lexicality [$F(1,124) = 4.22$, $MS_e = 0.02$, $p = .04$], state × age group [$F(3,124) = 3.06$, $MS_e = 0.03$, $p = .03$], and lexicality × age group [$F(3,124) = 3.28$, $MS_e = 0.02$, $p = .02$]. The two-way interactions involving age group are depicted in Figure 2. In terms of the changing-state conditions and the steady-state conditions, the changing-state effect was much larger in the younger children than in the adults. Also, the large word–tone difference of the younger children was not so clearly evident in the adults. The interaction of state and lexicality, which can be observed in Figure 1, indicates that the difference between words and tones was larger in the changing-state than in the steady-state conditions. The three-way interaction was not significant.

A more complete description of performance is provided by the effect of list length on the magnitude of the ISE. Matching the age groups for level of difficulty was very important for the observed age differences, as opposed to using a fixed list length. The means and standard deviations for the auditory conditions at each list length are shown in Table 3. The proportions correct in the serial recall task increased as list length decreased. The change in the magnitude of the disruption across list lengths was such

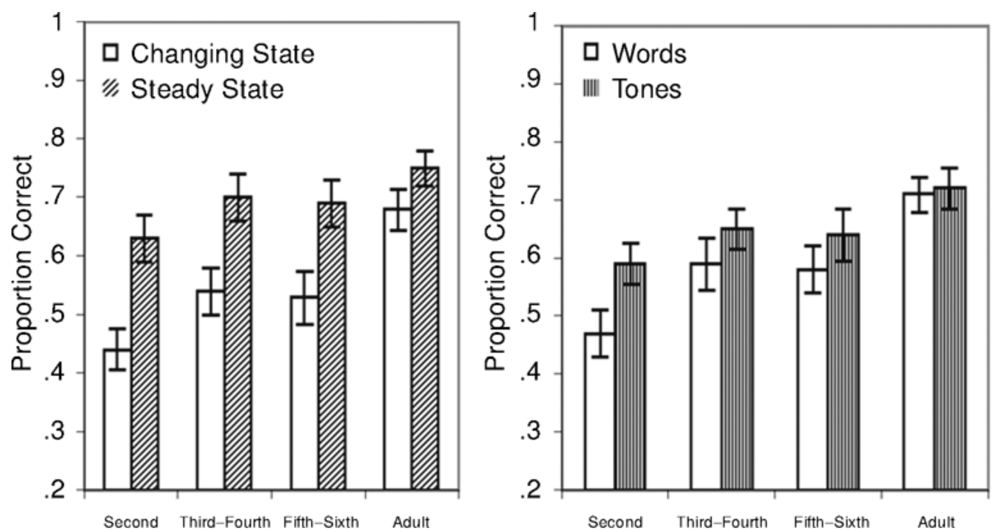

Figure 2. Age group means for the effects of changing-state and lexicality of the auditory conditions for lists of span length only. Error bars represent standard errors of the mean.

Table 3
Proportions Correct (PCs) and Standard Deviations for the Relative List Lengths in the Auditory Conditions

	Span		Span − 1		Span − 2		Span − 3	
	PC	*SD*	PC	*SD*	PC	*SD*	PC	*SD*
			Second Grade					
Silence	0.72	0.22	0.86	0.21	0.95	0.12	0.98	0.01
Changing word	0.34	0.20	0.58	0.24	0.82	0.21	0.94	0.13
Changing tone	0.53	0.18	0.78	0.23	0.94	0.12	0.97	0.07
Steady word	0.60	0.21	0.82	0.23	0.91	0.13	0.98	0.06
Steady tone	0.65	0.25	0.83	0.23	0.98	0.06	0.99	0.03
			Third–Fourth Grade					
Silence	0.75	0.21	0.91	0.13	0.99	0.03	0.97	0.08
Changing word	0.52	0.27	0.59	0.25	0.85	0.22	0.95	0.12
Changing tone	0.57	0.19	0.90	0.14	0.91	0.14	0.98	0.06
Steady word	0.66	0.25	0.82	0.21	0.93	0.14	0.99	0.02
Steady tone	0.73	0.25	0.89	0.19	0.98	0.08	0.99	0.06
			Fifth–Sixth Grade					
Silence	0.72	0.17	0.88	0.13	0.94	0.13	0.98	0.07
Changing word	0.49	0.25	0.67	0.28	0.78	0.17	0.91	0.17
Changing tone	0.57	0.26	0.76	0.19	0.89	0.15	0.97	0.08
Steady word	0.67	0.24	0.78	0.23	0.91	0.14	0.98	0.05
Steady tone	0.70	0.22	0.82	0.20	0.95	0.11	0.98	0.07
			Adult					
Silence	0.78	0.15	0.87	0.16	0.99	0.03	1.00	0.02
Changing word	0.67	0.19	0.82	0.17	0.88	0.14	0.96	0.08
Changing tone	0.70	0.20	0.90	0.11	0.95	0.08	0.98	0.04
Steady word	0.77	0.16	0.87	0.14	0.97	0.06	0.99	0.02
Steady tone	0.74	0.17	0.88	0.14	0.94	0.11	0.99	0.04

that by span minus 3, even in the changing-state words condition, participants in all age groups were performing at very high levels on the serial recall task (even though at lists of span length, the performance levels were quite different among the age groups).

Finally, an analysis of performance across the experimental trials was conducted to look for long-term habituation effects, as opposed to the short-term effects present at the level of each trial. The irrelevant-sounds task was presented in three blocks of 20 trials each. The repeated measures factor of block was entered into an analysis including auditory condition and the between-subjects factor of age group, creating a 3 × 5 × 4 ANOVA, collapsing across the factor of list length. The main effect of block was significant [$F(2,248) = 16.27$, $MS_e = 0.01$, $p < .001$], and a post hoc Newman–Keuls analysis revealed that performance improved significantly from Block 1 ($M = 0.82$) to Block 2 ($M = 0.85$), but remained at a steady level from Block 2 to Block 3 ($M = 0.85$). Tentatively supporting the hypothesis of habituation, the interaction of block by auditory condition was significant [$F(8,992) = 5.99$, $MS_e = 0.01$, $p < .001$]. The interaction revealed steady levels of performance across Blocks 2 and 3 in the auditory conditions containing steady-state distractors relative to the conditions containing changing auditory distractors, in which performance decreased from Block 2 to Block 3. The interaction of age group with blocks was not significant, which is consistent with the finding that children and adults both show comparable amounts of habituation (Tipper et al., 1989). Also, the three-way interaction was not significant, which again revealed no interactions of these effects with age group. The same pattern of results was found when separate analyses were done for each auditory condition. The means and standard deviations for the three trial blocks by each auditory condition are shown in Table 4. The values in the table are collapsed across list length and age group. Interpretation of this analysis may be tentative because the results were complicated by other possible effects, such as practice with the task.

DISCUSSION

The goals of this study were to examine developmental change in the effects of distracting sounds on a serial recall task and to assess current theories of the effects of irrelevant sounds on performance in light of developmental changes. With measures of performance in silence as a

Table 4
Means and Standard Deviations for Each Trial Block Within the Five Auditory Conditions Collapsed Across Age Groups and List Lengths

	Block					
	1		2		3	
Auditory Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*
Silence	0.88	.11	0.87	.13	0.93	.11
Changing-state words	0.72	.20	0.77	.18	0.74	.20
Changing-state tones	0.79	.14	0.88	.13	0.82	.16
Steady-state words	0.83	.15	0.87	.13	0.86	.14
Steady-state tones	0.86	.14	0.89	.14	0.88	.13

baseline for comparison, the main finding of this study was that children were more adversely affected by the presence of irrelevant sounds than were adults. Also, consistent with the literature (Chi, 1977; McCormack et al., 2000), with increasing age there were increases in span.

In the serial recall task with irrelevant sounds, the sounds impaired memory performance in all age groups. Auditory conditions with sounds that changed were more detrimental to serial recall performance than were conditions in which sounds were repeated. This changing-state effect was larger for the children than for the adults. For the children, but not the adults, speech sounds were more detrimental to performance than were the tones. A significant difference between speech and tones has not been consistently obtained in adults in the ISE literature. Although tones can impair performance, the relative amounts of disruption caused by speech versus tone stimuli has varied across experiments (Jones & Macken, 1993; Jones et al., 1993; LeCompte, 1994; LeCompte, Neely, & Wilson, 1997; Tremblay & Jones, 1998).

These findings of developmental differences in the effect of distracting sounds have implications for current theoretical approaches. The theories will be examined to determine which offers the best explanation for the present data set.

Automatic-Access Theories Without a Specified Role for Attention

Generally, the automatic-access theories without a specified role for attention would not predict the pattern of developmental *decreases* in the magnitude of the ISE, as were found in the present study. On the basis of Baddeley's (1986) model, as a result of changes in the way that children begin to recode stimuli with development, smaller effects of irrelevant speech in children were to be expected. This prediction was based on the logic that children have to first recode the visual stimuli verbally for the stimuli to be present in the phonological loop for a conflict between the relevant and irrelevant stimuli to occur.

The O-OER model might also be interpreted to predict smaller disruption by irrelevant sounds in young children. The O-OER emphasizes the rehearsal of the serial order of the visual items for the conflict among the auditory and visual items to occur. If young children rehearse in a less systematic way than adults, one would expect poorer recall relative to adults generally, but less of an ISE in children. The interaction of recall performance with auditory condition and age group suggests that the O-OER is not a completely satisfactory explanation for the present developmental findings.

Also, the finding of developmental change in the disruptive effects of speech and tones is problematic for the equipotentiality hypothesis of Jones, which describes functionally equivalent disruption by speech and tones. The adult data are consistent with the equipotentiality hypothesis of the O-OER model, but the children's data require an amendment of that theory.

Theories Including a Role for Attention

The findings of larger effects of irrelevant sounds in younger children are generally consistent with the developmental predictions of the two models that contain an attentional component. Cowan's model assumed that sounds that change are more disruptive because of deviation from any mental model that had been formed, which causes a recruitment of attention away from the visual stimuli. This disruption is compounded by poorer control of attention in younger children. The younger children may not have been able to use their attention to tag the relevant visual items, and thus distinguish them from the irrelevant items, as well as the older participants. Hence, the finding that the magnitude of the changing-state effect decreased with development is consistent with Cowan's model.

The difference between speech and tones was largest in the second graders, with a smaller difference between these conditions in the intermediate age groups (third–fourth and fifth–sixth graders), and no difference at all in adults. If speech demands greater attentional resources in children, then these developmental changes in the speech and tone conditions are consistent with the two models containing an attentional component, because of known developmental changes in attentional resources (Cowan et al., 1999).

However, there was not a difference between speech and tones in the adults. Cowan's model does not specify a difference between speech and tones explicitly. His model mainly emphasizes the changing-state effect with an attentional explanation. Although speech does have internal changes, this may be unimportant for recruiting attention in adults, who have greater familiarity with speech than the youngest children in this study. The changes within a word are smaller than the changes across words, and the tones used in this study did not change internally. If the changes within a word do not recruit attention in adults, and tones do not change internally, this leads to the expectation of no large differences between speech and tones in adults.

Neath's (2000) model explains the ISE in terms of interference by similar features that degrade the chances of correctly matching memory traces. Speech as the distracting stimulus shares more features (i.e., a phonological code) with the printed verbal stimuli that are to be recalled, and thus would interfere more than tones, which have no phonological code. As a result of this feature comparison process, the model would predict greater disruption by speech than by tones, which is consistent with the results of the youngest children in this study but not of the adults. The attentional parameter can be applied to explain the larger difference between speech and tones in the children, although a point should be made about the attentional parameter. Several factors might be attributed to the attentional parameter, such as the effects of changing-state sounds, the attentional control of the participant, and the task difficulty. The exact implementation of the attentional parameter is something that should be considered in future applications of the feature model.

Generally, adults were better able to avoid distraction from the irrelevant sounds than were the children. The changing-state conditions that produced the most disruption in the adults' performance resulted in severe disruption in the children's performance. The interactions of the effects with age provide evidence for a role of attention in avoiding distraction. This supports the two theories containing an attentional component, Cowan's (1995) memory framework and Neath's (2000) feature model.

The two automatic-access theories without a specified role for attention do not seem capable of handling these findings in their current state. For different reasons, neither of these theories predicted that young children would show greater disruption by irrelevant sounds than would the older participants. It seems that the sounds are entering the processing system automatically and that changing-state sounds may recruit attention at all ages. When this occurs, deliberate attentional control is most important; thus the changing-state sounds by age interaction. Beyond the stage of automatic entry, attention is used to mediate the disruption caused by irrelevant sounds. This would suggest that attention might act at the level of response selection in this task, an issue that has not been addressed by the theories without a specified role for attention.

Although Salamé and Baddeley (1982) did not find evidence of attentional distraction in the ISE in adults, these findings with children renew the issue. Individuals with poorer attentional control abilities may be more susceptible to the ISE. Recent attempts to understand developmental change within the context of the WM model have proven very beneficial for both studies of development and studies of working memory generally (Baddeley & Hitch, 2000). Perhaps the central executive component of the WM model could be applied to the effects of irrelevant sounds, instead of primarily relying on the phonological loop to explain the effects. It has been suggested that the central executive component is located primarily in the prefrontal cortex (Engle, Kane, & Tuholski, 1999), and this has been supported by findings from neuropsychology (D'Esposito et al., 1995). Developmental improvements in selective attention and inhibition have been linked, at least in part, to the maturation of the frontal lobes, which continue to develop into adolescence (Case, 1992; Dempster, 1993). Thus, developmental changes in the central executive component of Baddeley's WM model might explain the developmental decreases in the detrimental effects of irrelevant sounds.

According to this type of explanation, one might expect a larger disruptive effect of irrelevant sounds in older adults than in young adults due to differences in inhibitory abilities with aging (Hasher, Stoltzfus, Zacks, & Rypma, 1991). Rouleau and Belleville (1996) conducted a study that directly addressed this issue and did not find differential disruptive effects of irrelevant speech in a sample of young adults and older adults. However, one must consider whether a direct comparison between the cognitive abilities of older adults and young children is a fair one. The difference between older adults and young adults is not as extreme of a group difference as the difference between young adults and young children. For example, in the Rouleau and Belleville study, the older adults had memory span scores of approximately 6 items. In the present study, the youngest children had integer span scores of 5 items, and the adults recalled 7.5 items.

Conclusions

In conclusion, the present study demonstrated greater detrimental effects of distracting sounds on the performance of children. The theories containing a role for attention (Cowan, 1995; Neath, 2000) seem best suited to handle the findings from this developmental study. The existing explanations of the effects of irrelevant sounds need to be reconsidered in light of these developmental differences. These findings have exciting implications for future research as well as for theories of the effects of irrelevant sounds on performance. Understanding the basis of the disruption by irrelevant sounds will contribute to our understanding of the interaction of memory and attention and also to our understanding of developmental change in these areas.

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