# Irrelevant Speech Disrupts Item-Context Binding

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# Abstract

The present study examines the effects of irrelevant speech on immediate memory. Previous research led to the suggestion that auditory distractors particularly impair memory for serial order. These findings were explained by assuming that irrelevant speech disrupts the formation and maintenance of links between adjacent items in a to-be-remembered sequence, resulting in a loss of order information. Here we propose a more general explanation of these findings by claiming that the capacity to form and maintain item-context bindings is generally impaired by the presence of auditory distractors. The results of Experiment 1 show that memory for the association between an item and its background color is drastically impaired by irrelevant speech, just as memory for the association between an item and its serial position. In Experiment 2 it was examined whether the disrupting effects of irrelevant sound are limited to memory for item-context associations or whether item memory is also affected by the auditory distractors. The results revealed that irrelevant speech disrupts both item memory and item-context binding. The results suggest that the effects of irrelevant sound on immediate memory are more general than previously assumed, which has important theoretical and applied implications.

Keywords: Auditory Distraction, Attentional Capture, Memory Binding, Working Memory, Recollection, Irrelevant Sound Effect, Irrelevant Speech Effect

# Irrelevant Speech Disrupts Item-Context Binding

It is well known—from personal experience and scientific evidence—that to-be-ignored distractor sounds interfere with cognitive activities. Consensus has been reached that interference is largely determined by the variability of the auditory distractors (e.g., Näätänen, 1990). Abrupt changes are particularly hard to ignore. For instance, unexpected auditory deviants that differ significantly from previous stimulation capture attention and interfere with visual primary tasks (e.g., Escera, Alho, Schröger & Winkler, 2000).

Behavioral research has been dominated by the irrelevant-sound paradigm (Colle & Welsh, 1976) in which participants see short lists of items (digits, letters, or words) in quiet or while ignoring task-irrelevant auditory distractors (tones, environmental sounds, words, or continuous speech). The auditory distractors typically disrupt short-term memory for these lists severely. Changing-state sequences consisting of changing sounds or words disrupt performance more than steady-state sequences consisting of repetitions of the same sound or word (Bell, Dentale, Buchner & Mayr, 2010; Campbell, Beaman & Berry, 2002; Jones, Madden & Miles, 1992). Several explanations have been put forward for the marked disruption of visual short-term memory by changes in the auditory modality.

## The attention-capture account

According to the embedded processes model (Cowan, 1995), abrupt auditory changes elicit an orienting reaction, as a result of which the focus of attention is temporarily drawn away from the primary task. Steady-state sequences interfere less with performance than changing-state sequences because the orienting reaction is attenuated with repeated exposure to the same auditory stimulus features. Psychophysiological studies on the irrelevant sound effect (ISE) are most consistent with this explanation (Bell et al., 2010; Chein & Fiez, 2010; Little, Martin & Thomson, 2010; Schlittmeier, Weisz & Bertrand, 2011; Weisz & Schlittmeier, 2006). For instance, the detrimental effect of changing distractors is associated with an enhanced N1 response to the distractors, which is often seen as an electrophysiological correlate of a "call for attention" (Bell et al., 2010; Campbell, Winkler & Kujala, 2007; Campbell, Winkler, Kujala & Näätänen, 2003), and with an increased P3a (Bell et al., 2010), which is often interpreted as a correlate of an attention switch to the auditory modality in cross-modal distraction paradigms (e.g., Escera et al., 2000). Furthermore, a reduction in theta and gamma power has been observed as a result of auditory distraction, which could reflect a withdrawal of attentional resources from the primary task (Schlittmeier et al., 2011;

Weisz & Schlittmeier, 2006). The attentional hypothesis is also supported by recent evidence that the ISE decreases with repeated exposure to the auditory distractors, at least under some circumstances (Bell et al., 2012).

## The order-interference account

Competing theories claim that the ISE is not caused by attentional capture, but rather by an interference of the preattentive processing of the auditory distractors with similar processes needed for the short-term rehearsal of the target material. Most importantly, the object-oriented episodic record (O-OER) model (Jones, 1993) states that the ISE is due to an interference of order processing. Often, the serial-recall task requires recalling small sets of target items drawn from familiar categories (such as the digits 1-9) throughout the experiment. Hence, if interference occurs, the difficulty is not remembering the item information, but the order in which the items were presented. According to the O-OER model, the ISE is caused by automatic interference of two types of order information. First, the order of the target items is represented by establishing and maintaining links between temporally adjacent items. Second, the to-be-ignored auditory sound stream is pre-attentively segmented into different auditory objects whenever abrupt changes in the sound characteristics occur. Links representing the order of these auditory distractor objects are automatically generated by an obligatory seriation process. The order information resulting from the obligatory seriation of the objects forming the auditory stream interferes with the maintenance of the target item links. An implication of this order interference hypothesis is that the ISE should be limited to tasks that require the processing of serial order.

## The task specificity of the ISE

Due to the strong influence of the link interference account, tasks examining irrelevant-sound interference were usually designed to rely heavily on order memory. In most studies, the standard serial-recall procedure was used (e.g., Beaman, 2005; Bell & Buchner, 2007; Buchner, Bell, Rothermund & Wentura, 2008; Campbell et al., 2002; Jones & Macken, 1993; Jones, Macken & Murray, 1993). Other studies employed order recognition tasks that pose even less demands on item memory, and more emphasis on order memory (Gisselgard, Udden, Ingvar & Petersson, 2007; Hadlington, Bridges & Darby, 2004). In a typical order recognition task, the previously presented sequence is presented again, and participants are asked whether two adjacent items of the sequence have been transposed or not. In some studies (Beaman, Neath & Surprenant, 2008; Schlittmeier et al., 2011; Tremblay, Macken & Jones, 2000; Weisz & Schlittmeier, 2006), the previously presented items were simultaneously shown on screen, and participants were required to click on the items in the order of presentation. In other studies, participants were asked to draw lines from the pictures of the previously presented objects to numbers indicating the serial positions of these objects (Klatte, Lachmann, Schlittmeier & Hellbrück, 2010). In a study of Beaman and Röer (2009), participants were required to “drag and drop” words in a response box indicating the serial position of the items. Just like studies using the standard serial recall procedure, these studies revealed marked decrements in order memory due to the presentation of variable auditory distractors, regardless of whether the temporal order of digits, words, pictures or spatial positions had to be remembered (e.g., Bell et al., 2010; Buchner et al., 2008; Jones, Farrand, Stuart & Morris, 1995; Klatte et al., 2010). Consequently, most of these studies were interpreted as providing evidence in favor of the order interference hypothesis.

However, in order to prove that the effect is indeed due to a disruption of order memory, it is necessary to show that tasks that do not rely on order memory are insensitive to the disruptive effects of irrelevant sound. The evidence regarding this question is mixed (e.g., LeCompte, 1994; Stokes & Arnell, 2012). There is evidence that tasks that do not obviously require order processing such as free recall are disrupted by irrelevant speech, but the distraction may still be mediated by a disruption of serial rehearsal (Beaman & Jones, 1998). Evidence in support of the order interference view has been obtained using a missing item task (Beaman & Jones, 1997; Hughes, Vachon & Jones, 2007; Jones & Macken, 1993) in which participants are presented with lists of items that are drawn from a small familiar set (e.g., the digits 1-9). On each test trial, one of the items of the set is missing from the list, and participants’ task is to identify the missing item. The missing item task seems to be less sensitive to the disruptive effect of changing auditory distractors. Some studies found no effect of changing sounds on the missing item task (Hughes et al., 2007; Jones & Macken, 1993), and others found small and unreliable effects (Beaman & Jones, 1997). These findings stand in marked contrast to those showing a high sensitivity of order memory for irrelevant-sound interference. Given that the missing item task does not rely on order memory, the usual interpretation of this dichotomy is that tasks that do not require order processing are insensitive to the detrimental effects of irrelevant sound. Therefore, these findings support the hypothesis that the ISE is a special form of interference due to the conflict of two types of order information.

However, alternative interpretations of this dissociation are possible. The distinction between the missing item task and the order memory tasks is reminiscent of the distinction between item memory and associative memory. To identify the item that is missing on a previously presented list, only item memory is necessary. In other words, the missing item task can be solved by relying solely on item familiarity. By contrast, order memory tasks do not rely on item memory, but instead require participants to remember the temporal context in which the items were presented (e.g., associations between adjacent items in the list). Given that associative memory is known to be more fragile (e.g., E. Brown, Deffenbacher & Sturgill, 1977) and more dependent on attentional resources (e.g., Troyer, Winocur, Craik & Moscovitch, 1999) than item memory, it is not entirely surprising that memory for the temporal context is more easily disrupted by irrelevant sound than item memory. Thus, the data pattern could be reconciled with the attention-capture view of the ISE by assuming that irrelevant speech disrupts item-context binding in general.

It is commonly assumed that attention and binding are closely related. In perception, it has long been established that focal attention is necessary to “glue” together multiple features to built a coherent object representation (Treisman, 2003; Treisman & Gelade, 1980). Recollection, in contrast to familiarity-based recognition, is characterized by an integration of an information with its context (Meiser & Bröder, 2002; Meiser, Sattler & Weisser, 2008; Oberauer, 2005; Perfect, Mayes, Downes & Van Eijk, 1996). Furthermore, it has been shown that a reduction of attentional resources disrupts the formation and maintenance of bindings in short-term memory (L. A. Brown & Brockmole, 2010; Elsley & Parmentier, 2009; Wheeler & Treisman, 2002). Several working memory models include the assumption that one of the main functions of the focus of attention is the binding of information to generate integrated episodic representations. This would include the binding of information to its temporal context (e.g., its ordinal position in the list), as required by serial order memory tasks. A reduction in attentional working-memory resources—due to aging (L. A. Brown & Brockmole, 2010; Oberauer, 2005), limited working memory capacity (Elsley & Parmentier, 2009; Oberauer, 2005), or distraction (L. A. Brown & Brockmole, 2010)—would therefore lead to a diminished ability to form and memorize bindings between content (item) and context information.

An implication of this view is that the binding of item information to other context features (e.g., perceptual features or the spatial context) might be disrupted as well. In the present study, we provide evidence that item-context binding is generally disrupted by irrelevant speech. In the item-order association group, participants’ task was to recall the serial order of items while ignoring irrelevant speech. We expected to replicate the finding of Beaman and Röer (2009) that this task is severely disrupted by speech distractors. In the item-color association group, a similar experimental procedure was used, but participants’ task was to remember the background color associated with each item. Note that order memory is completely irrelevant for the second task, which instead requires memory for the association between an item and perceptual features of its background. Thus, the order interference view predicts that only the order memory task, but not the color memory task, should be severely impaired by irrelevant speech. In contrast, the binding disruption hypothesis predicts that the ISE is not limited to the bindings of items to their temporal context, but should generalize to other forms of bindings such as that of an item to the color context in which it was experienced. Therefore, both tasks should be severely impaired by the auditory distractors.

# Experiment 1

## Method

### *Participants*

Fourty-seven students at Heinrich Heine University Düsseldorf (33 female; 14 male; mean age = 24.79, *SD* of age = 4.24) were randomly assigned to the item-order association group ($n$ = 23) or the item-color association group ($n$ = 24).

### *Materials and Procedure*

Each trial started with the presentation of an exclamation mark, alerting the participant that a trial was about to begin. Then, the seven letters B, H, J, Q, V, X, Z, were presented one after another in random order at the center of the screen in 200 pt plain Helvetica font. Each letter was presented in a colored 330 pt × 335 pt rectangle, the color of which was either yellow, orange, red, purple, blue, green, or gray. Each letter was randomly assigned to a different background color. The letters were presented for 1000 ms with a 500 ms inter-word interval. Immediately after the presentation of each list, an item-context association test started.

The item-order association test was very similar to that used by Beaman and Röer (2009). The letters were displayed in alphabetical order at the center of the screen (Figure 1, Panel A). Participants had to remember the serial order in which the letters had been presented. They were asked to “drag and drop” the letters into the response boxes that were labeled with the serial positions, using the computer mouse. Answers could be corrected by clicking a “delete” button below the response boxes, in which case the letter was deleted from the response box and reappeared at its former position in the center of the screen. After all letters were assigned to serial positions, participants started the next trial by clicking a “continue” button. After each trial, a visual feedback was shown informing participants how many items were correctly remembered.

The item-color association test was identical to the item-order association test except that participants were required to remember the background color instead of the serial position of each item (Figure 1, Panel B). Participants in the item-order association group knew that the color information was irrelevant, and participants in the item-color association group knew that the order information was irrelevant.

Participants knew that the auditory distractors should be ignored. The experiment started with five quiet practice trials. The experiment proper consisted of 12 quiet control trials and 12 irrelevant-speech trials, the order of which was randomized. In the irrelevant speech condition, participants heard a stream of words that were drawn from the following set of one-syllable words (translation in brackets): Alm [alp], Elch [moose], Gel [gel], Jod [iodine], Los [lot], Milz [spleen], Ohm [ohm], Schopf [tuft], Steg [plank], Streu [mulch], Tau [dew], Zwist [srife]. These auditory distractors caused pronounced distraction effects in previous studies (Bell et al., 2012; Röer, Bell, Dentale & Buchner, 2011). The word recordings were spoken by a female voice and recorded digitally at 44.1 kHz with 16-bit encoding, edited to last 600 ms, and normalized to minimize amplitude differences among the stimuli. The sounds were played through headphones at an average sound level of about 75 dB(A) $L_{eq}$. The distractors were randomly selected, but adjacent distractors were always different from each other.

*Design*

The level of significance was set to .05 for all analyses. The most important question was whether we could replicate the classical ISE in the item-color association group, or whether such an effect would be absent. Note that an effect of the same size as the one obtained in Beaman and Röer's (2009) Experiment 2 ($d_z$ = 1.61) could be detected with sufficient statistical power (1- β = .95) using a sample size of only *n* = 8 participants. However, given that we aimed to demonstrate a novel effect, we thought it would be desirable to use a larger sample size of at least *n* = 23 in each group to be able to detect even somewhat smaller effects ($d_z$ = 0.80) with sufficient statistical power.

## Results

When the data of both groups were analyzed together[1], there was a significant main effect of task, $F(1,45) = 23.56$, $p < .01$, $\eta^2 = .34$, and irrelevant speech, $F(1,45) = 48.88$, $p < .01$, $\eta^2 = .52$, but no interaction between task and irrelevant speech, $F(1,45) = 2.42$, $p = .13$, $\eta^2 = .05$. Thus, both tasks were equally disrupted by the auditory distractors (Figure 2).

Specifically, performance in the item-order association group was worse when irrelevant-speech distractors were played during encoding, $t(22) = 5.34$, $p < .01$, $d_z = 1.11$. This finding confirms the typical ISE on order memory for the present experiment.

Most importantly, there was also a significant ISE in the item-color association group, $t(23) = 4.47$, $p < .01$, $d_z = 0.91$. This finding confirms that irrelevant speech interfered with item-context binding in general, regardless of whether the temporal context or the color context had to be remembered.

## Discussion

Experiment 1 replicates the finding of Beaman and Röer (2009) and many others that memory for order is disrupted by irrelevant speech. However, inconsistent with the predictions of the order interference account, the effect was not limited to the item-order association task. Instead, there was a marked disruptive effect of irrelevant speech on memory for the association of an item to its background color. This novel finding suggests that irrelevant speech might generally interfere with item-context binding.

Experiment 2 served two aims. First, it seemed desirable to replicate this novel finding. Second, we have proposed that previous findings can be explained by assuming that item memory is less affected by irrelevant speech than memory for item-context associations. However, Stokes and Arnell (2012) have shown that irrelevant speech interfered with a surprise nonserial old-new recognition task even when participants were unaware of the need to rehearse the items for a later memory test, which suggests that item representations can also be impaired by irrelevant speech (see also LeCompte, 1994). Therefore, we wanted to test whether item memory is also affected by irrelevant sound distractors.

In Experiment 1, the item-context association test did not require item memory at all, because all target items were presented at test, and there was no need to discriminate the list items from new ones. Therefore, Experiment 1 provides clear evidence for an ISE on item-context association memory, but the results cannot help to shed light on the question whether item memory is immune to the disruptive effects of irrelevant speech. In Experiment 2, the experimental paradigm was changed to allow for an assessment of memory for both item-context bindings and items. We expected to replicate the finding of Experiment 1 that memory for item-context associations is severely disrupted by irrelevant speech. Given the mixed findings in the literature, it was less clear whether auditory distractors would affect item memory or not.

# Experiment 2

## Method

### *Participants*

Fifty-eight students (41 female; 17 male; mean age = 23.43, *SD* of age = 4.33) were randomly assigned to either the item-order association group ($n$ = 29) or to the item-color association group ($n$ = 29).

### *Materials, Procedure and Design*

Materials and procedure were identical to those of Experiment 1 with the following exceptions. A total of 406 common one-syllable words were selected from the CELEX database (Baayen, Piepenbrock & van Rijn, 1993) to serve as visual targets (e.g., “Bar”, “Bus”, “Land”, “Sport”, “Text”, “Jazz”, “Zoo”). In each trial, the target list consisted of a new set of seven words drawn randomly without replacement from that pool. The words were presented one after another in colored rectangles. In the item-context association tests, the seven words of the list were presented together with seven new words at the center of the screen. The position of the fourteen words on the screen was randomly determined. Participants’ task was to “drag and drop” the seven words that were previously presented into the correct response boxes. In the item-order association group, the task was to assign the words to the correct serial positions. In the item-color association group, the task was to assign the words to the correct background colors. After participants had dropped seven of the 14 words into the seven response boxes, a “continue” button appeared. Participants clicked this button to see the feedback, and to start the next trial. The auditory distractor sounds were played at an average sound level of about 65 dB(A) $L_{eq}$.

A power analysis showed that the ISE on item-color association memory obtained in Experiment 1 ($d_z$ = 0.91) could be detected with sufficient power ($1 - \beta = .95$) with a sample size of only $n$ = 15 participants. However, we thought it desirable to have a larger sample size to be able to detect somewhat smaller effects of irrelevant speech on item recognition ($d_z$ = 0.70) and recruited $n$ = 29 participants in each group.

## Results

*Item Memory.* Item memory was measured in terms of old-new recognition hit rates (the mean proportion of items correctly recognized as old, irrespective of their order). There was a main effect of group, $F(1,56) = 13.11$, $p < .01$, $\eta^2 = .19$, and of irrelevant speech, $F(1,56) = 22.96$, $p < .01$,

$\eta^2 = .29$, but no interaction between group and irrelevant speech, $F(1,56) = 2.87$, $p = .10$, $\eta^2 = .05$ (Figure 3). Irrelevant speech disrupted item memory in the item-order association group, $t(28) = 4.72$, $p < .01$, $d_z = .88$, and in the item-color association group, $t(28) = 2.13$, $p = .04$, $d_z = .40$.

*Memory for item-context associations*. Figure 4 shows item-context association scores that are conditionalized on old-new recognition (i.e., the number of old items that were assigned to the correct serial position or color divided by the number of items correctly recognized as old). There was a main effect of group on the conditionalized item-context association scores, $F(1,56) = 17.20$, $p < .01$, $\eta^2 = .24$, and a main effect of irrelevant speech, $F(1,56) = 27.72$, $p < .01$, $\eta^2 = .33$, but no interaction between group and irrelevant speech, $F(1,56) = 0.09$, $p = .76$, $\eta^2 < .01$.

Specifically, and replicating the effects of irrelevant speech on order memory obtained in Experiment 1, there was a significant main effect of irrelevant speech on the conditionalized item-order association scores, $t(28) = 4.83$, $p < .01$, $d_z = .90$. The most interesting question was whether we would also replicate the finding of Experiment 1 that a similar disruption of memory could be found in the item-color association task. Indeed, there was a significant effect of irrelevant speech on the conditionalized item-color association scores, $t(28) = 3.04$, $p < .01$, $d_z = .57$.

## Discussion

Experiment 2 perfectly replicated the results of Experiment 1. Irrelevant speech disrupted memory for item-color associations as well as memory for item-order associations.

Extending the results of Experiment 1, Experiment 2 showed that the effects of irrelevant speech were not limited to item-context binding. Item memory was also impaired by irrelevant speech. This finding fits with that of a previous study showing that old-new recognition is impaired by irrelevant speech even when the memory test is not expected, and a rehearsal of the target items is unlikely (Stokes & Arnell, 2012). This result suggests that item representations can also be impaired by the presence of irrelevant speech at encoding, which is most compatible with an attentional explanation of the ISE (Stokes & Arnell, 2012). Cowan (1995) postulated that the short-term maintenance of items in a highly accessible state is accomplished by willfully bringing these items into the focus of attention. Therefore, a reduction of attention due to distraction may result in less accessible item representations in addition to the binding deficit.

Interestingly, there was also a main effect of the context-memory task on item memory. It could be that the order memory task encouraged a serial-rehearsal strategy that had a beneficial effect on item memory, but a priori we had no hypotheses about this, so any explanation of this finding would be speculative.

# General Discussion

The present results clearly confirm that the ISE is not restricted to tasks that rely on order memory. Two types of tasks were compared. In an item-order association task, participants were presented with a list of items in colored backgrounds, and were required to reconstruct their serial order. In the item-color association task, participants were asked to remember the background color of the items instead of their order. The predictions of the order interference account are straightforward. This account implies that the ISE is solely due to interference of order information. Therefore, the item-order association task should be drastically disrupted by irrelevant speech, whereas the item-color association task must be immune to auditory distraction. The present results are clearly inconsistent with these predictions. Memory for the associations between items and background colors was severely disrupted by irrelevant speech. Thus, the ISE is not limited to order memory.

The most straightforward explanation of these findings is that irrelevant sound disrupts short-term memory binding in general. This assumption does not contradict the order interference account, but rather generalizes it. The order interference hypothesis implied by the O-OER model (Jones, 1993) states that irrelevant speech disrupts the creation and maintenance of links between adjacent items, resulting in a loss of order information. Previous research has shown that this effect does not depend on a verbal recoding and rehearsal of the to-be-remembered items—it was also found with visual target material that could not be verbally recoded (Jones et al., 1995). The present results suggest that irrelevant speech disrupts not only the links between adjacent items in a serial order task, but generally the binding of an item to its context such as the background color. This binding disruption hypothesis receives further support by the finding of LeCompte (1994) that auditory distractors cause a performance decrement in a paired-associate memory task.

The results are compatible with a general attention-and-memory framework such as the embedded-processes model (Cowan, 1995). It is often assumed that the creation and maintenance of bindings within short-term memory depends on focal attention (L. A. Brown & Brockmole, 2010; Elsley & Parmentier, 2009; Wheeler & Treisman, 2002). For instance, Oberauer (2005) discussed whether building and maintaining novel bindings between memory representations is one of the main functions of the focus of attention. If auditory distractors divert attention away from the primary task, then the binding of an item to its context and the maintenance of these bindings in short-term memory may be generally impaired.

A different type of binding explanation of the ISE was recently proposed by Tremblay, Parmentier, Hodgetts, Hughes and Jones, (2012) who found that memory for the serial order of verbal material (letters) and memory for the serial order of the spatial locations were impaired by irrelevant speech, independent of whether or not the participants possessed foreknowledge about the type of material they had to remember. Based on these results, it was speculated that memory for the serial order of the spatial locations may have been rendered sensitive to the detrimental effects of verbal distractors because the spatial information became perceptually integrated with the to-be remembered verbal material at encoding. In other words, verbal material may be especially vulnerable to interference from verbal distractor material, and this sensitivity to distraction may "spill over" to other (e.g., spatial) features of the verbal material. This interference-transfer hypothesis might also be applied to explain why to-be-ignored verbal material interferes with memory for associations between verbal items and their context features (background color in the present case). However, an explanation of the ISE that is based on interference of verbal material is problematic because it has been shown that the ISE can be obtained with to-be remembered material that is difficult to verbalize (Jones et al., 1995), and does not depend on the use of verbal distractor material (e.g., Buchner et al., 2008; Jones & Macken, 1993; Tremblay, Nicholls, Alford & Jones, 2000).

The possibility that irrelevant speech generally disrupts item-context binding opens avenues for future research. A first step may be to examine whether the disruption of memory for item-color associations is sensitive to the same kind of manipulations as the original irrelevant sound effect. The theoretical views suggested here lead to the prediction that changing-state irrelevant speech should disrupt item-color binding more than steady-state speech. Furthermore, given that recent research (Hughes, Vachon & Jones, 2005) suggests that attentional capture disrupts encoding, but leaves the maintenance of order information in memory intact, it would be interesting to examine whether the disruptive effect of irrelevant sound is restricted to the encoding of item-color bindings. A second step could be to generalize the finding to other types of item-context bindings (e.g., memory for spatial locations), and to examine the influence of auditory distraction on other tasks that require memory for integrated episodic episodes (e.g., context-dependent memory).

In summary, we have proposed the simple hypothesis that the impairment of serial order memory by auditory distractors is a special case of a general disruption of the formation and maintenance of item-context bindings in short-term memory. Based on this hypothesis, we predicted that the ISE generalizes to memory tasks that rely on other types of item-context associations. Indeed, the results of two experiments showed that the memory for the association of items to their background colors was impaired by auditory distractors, suggesting that the ISE is a more general phenomenon than previously thought. This finding has important applied implications. Auditory distraction by variable sound distractors is not limited to tasks that rely on memory for serial order (i.e., remembering telephone numbers). Rather, irrelevant sound interferes with basic functions of memory that are relevant for a wide range of daily activities.

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# Figure Captions

*Figure 1:* Screenshots of the item-context association tasks. Panel A: An example of the item-order association task. The target letters are shown at the center of the screen. The participant's task was to "drag and drop" the items into the correct response boxes labeled with the serial positions 1-7. Panel B: An example of the item-color association task. The participant's task was to "drag and drop" the items into the correct response boxes labeled with the background colors. Two letters (J, and X) have already been assigned to background colors (yellow, and orange).

*Figure 2:* Proportion of correctly remembered items (assigned to the correct response boxes) in Experiment 1 as a function of task (item-order association vs. item-color association), and distractor condition (silence vs. speech). The error bars represent the standard errors of the means.

*Figure 3:* Item memory (the proportion of items that were correctly identified as "old", irrespective of whether the context was correctly remembered) as a function of task (item-order association vs. item-color association) and distractor condition (silence vs. speech) in Experiment 2. The error bars represent the standard errors of the means.

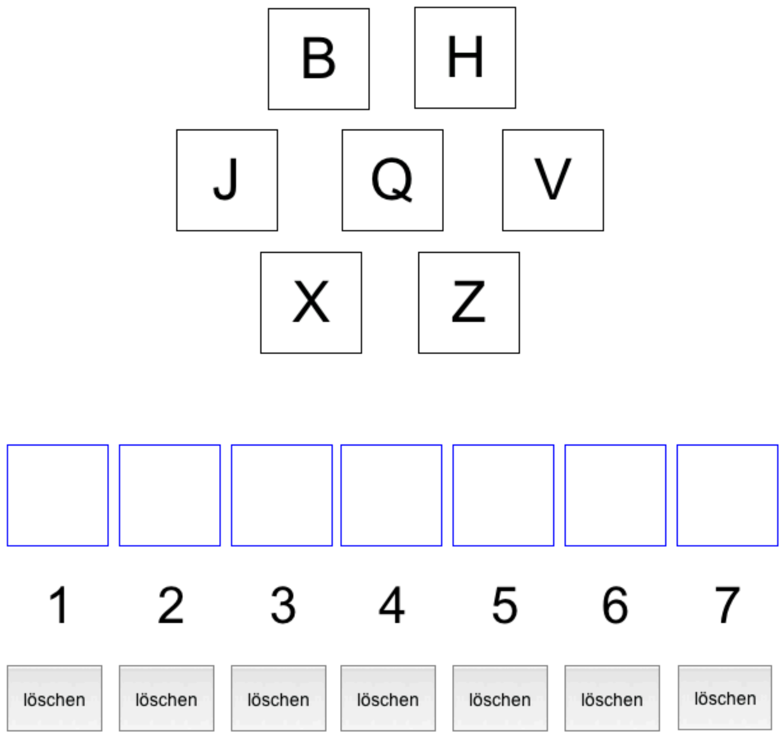
*Figure 4:* Item-context association memory (the number of items assigned to the correct serial position or background color, conditionalized on the number of hits) as a function of task (item-order association vs. item-color association), and distractor condition (silence vs. speech) in Experiment 2. The error bars represent the standard errors of the means.

# Footnotes

[1] A multivariate approach was used for the within-subjects comparisons. The present application represents a special case in which all multivariate test criteria correspond to the same exact (and not approximate) *F* statistic, which is reported. Partial eta squared values are reported as a measure of effect size.

Figure 1

A)


B H
J Q V
X Z
1 2 3 4 5 6 7
löschen löschen löschen löschen löschen löschen löschen

B)

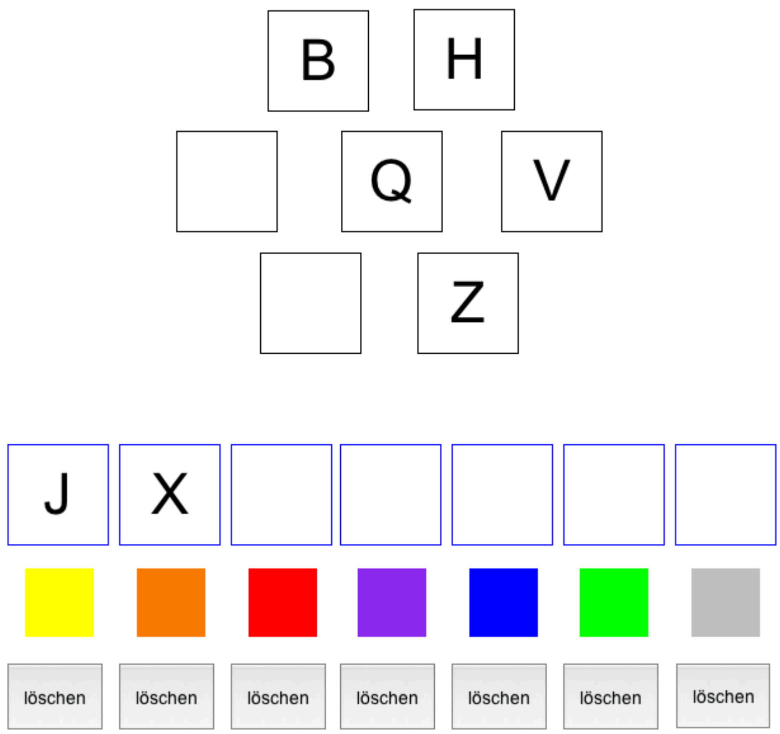
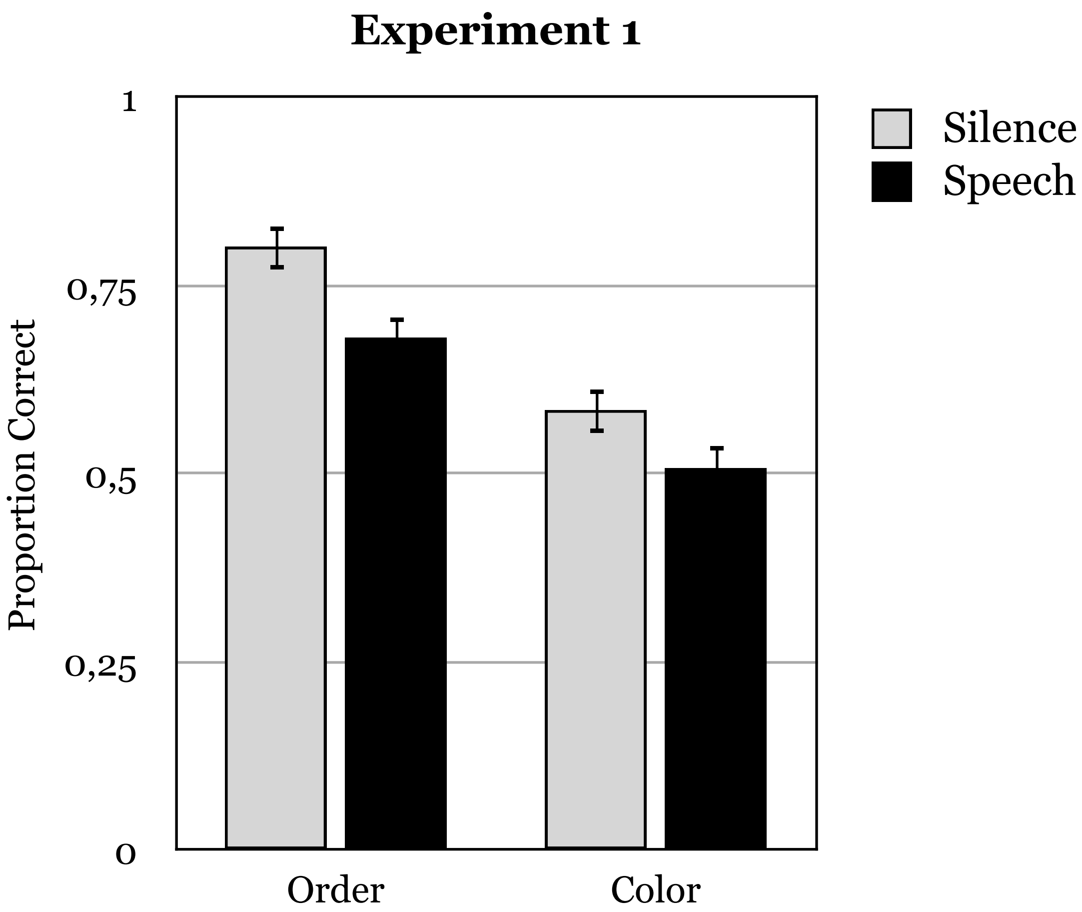

B H
Q V
Z
J X
löschen löschen löschen löschen löschen löschen löschen

Figure 2



Experiment 1
1
0,75
0,5
0,25
0
Proportion Correct
Order
Color
Silence
Speech

Figure 4

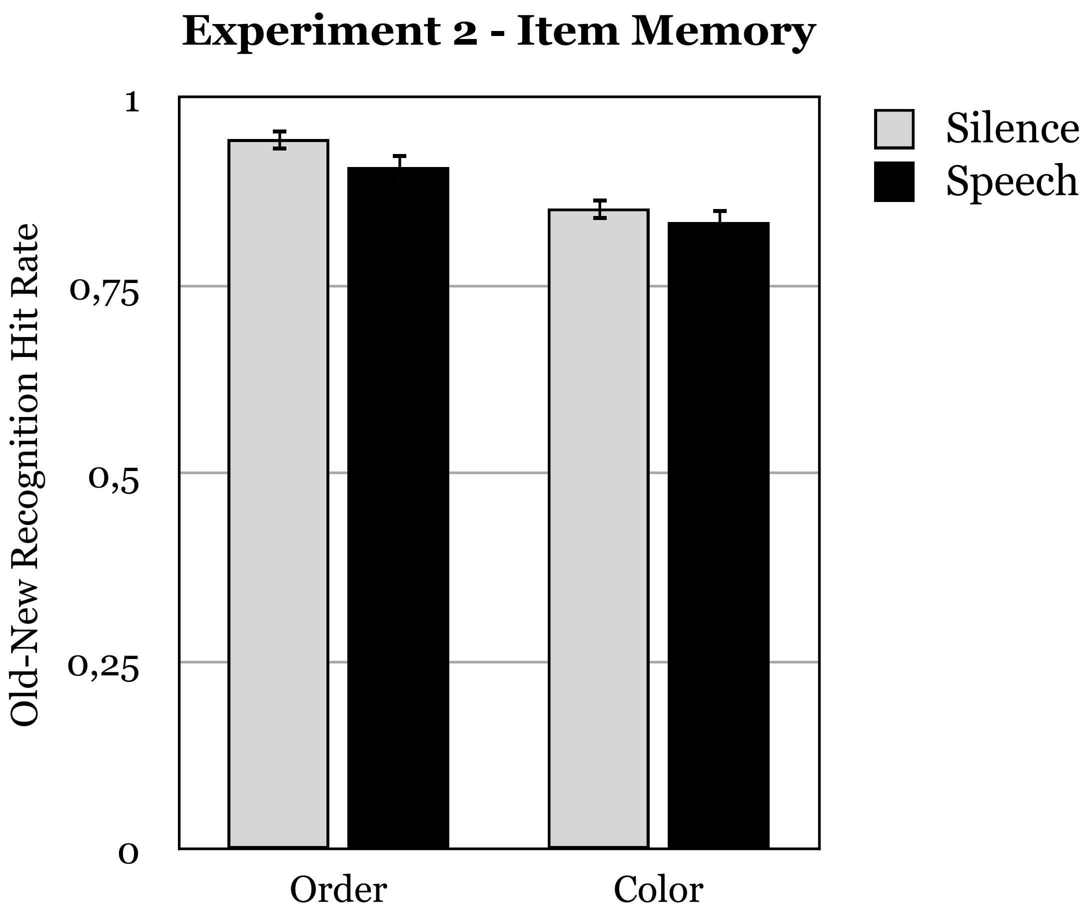
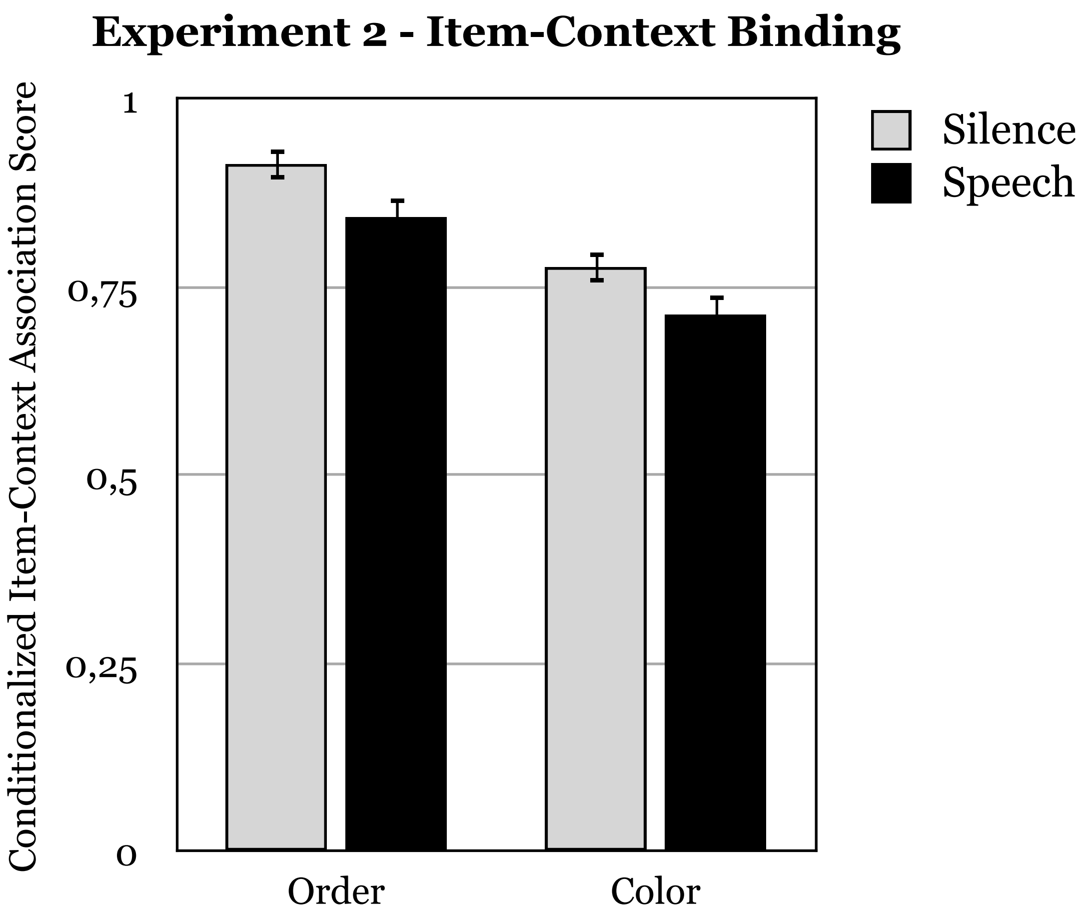

Experiment 2 - Item Memory
1
0,75
0,5
0,25
0
Old-New Recognition Hit Rate
Order
Color
Silence
Speech

Figure 5


Experiment 2 - Item-Context Binding
Conditionalized Item-Context Association Score
1
0,75
0,5
0,25
0
Order
Color
Silence
Speech