Evidence for habituation of the irrelevant sound effect on serial recall

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Abstract

Working memory theories make opposing predictions on whether the disruptive effect of task-irrelevant sound on serial recall should be attenuated after repeated exposure to the auditory distractors. While there is evidence of habituation after a passive listening phase, previous attempts to observe habituation to to-be ignored distractors on a trial-by-trial basis have proven to be fruitless. The present study suggests that habituation to auditory distractors occurs, but has often been overlooked, because past attempts to measure habituation in the irrelevant sound paradigm were not sensitive enough. In a series of four experiments the disruptive effect of to-be-ignored speech and music relative to a quiet control condition was markedly reduced after eight repetitions, regardless of whether trials were presented in blocks (Experiment 1) or in random order (Experiment 2). The auditory distractor's playback direction (forward, backward) had no effect (Experiment 3). The same results were obtained when the auditory distractors were only presented in a retention interval after the presentation of the to-be-remembered items (Experiment 4). This pattern is only consistent with theoretical accounts that allow for attentional processes to interfere with the maintenance of information in working memory.

Keywords: irrelevant sound effect, working memory, attentional orienting, serial recall, selective attention

Evidence of habituation to irrelevant sound

A basic feature of the auditory system is that it is always “open” for environmental information. Unlike in the visual system ears cannot be “closed” to regulate the sensory input. This incapability facilitates the detection of potentially relevant, but previously unattended information. However, the auditory system’s openness comes at the cost of enhanced distractibility (e.g., Escera, Alho, Schröger & Winkler, 2000). To-be-ignored auditory information usually disrupts ongoing task performance (Beaman, Neath & Surprenant, 2008; Bell, Röer & Buchner, 2013; Elliott & Briganti, 2012; Schlittmeier, Weisz & Bertrand, 2011; Sörqvist, Nöstl & Halin, 2012)

The irrelevant sound effect

The irrelevant sound effect refers to the disruption of serial recall by auditory distractors. Distraction is equally large regardless of whether the irrelevant sound is played during list presentation or during retention (Buchner, Bell, Rothermund & Wentura, 2008; Buchner, Rothermund, Wentura & Mehl, 2004; Miles, Jones & Madden, 1991), indicating that item maintenance in working memory is impaired, and not only encoding. Disruption is predominantly determined by the number of changing states (abrupt changes in frequency or amplitude) within the distractor sequence. The changing state effect refers to the phenomenon that changing state sequences consisting of different distractor items (lists of words, speech, melodies) impair serial recall more than steady state sequences consisting of a single repeated item. Accordingly, speech and non-speech sounds cause equal amounts of disruption (Jones & Macken, 1993; Tremblay, Nicholls, Alford & Jones, 2000) when they contain the same amount of acoustic variability. Lastly, sequences with deviant distractors (such as a distractor word spoken in a different voice) are known to disrupt serial recall more than sequences without deviant distractors (Hughes et al., 2005; Lange, 2005; Vachon, Hughes & Jones, 2012).

Habituation to auditory distractors

Despite the consensus in most of the phenomenon’s key aspects, there is disagreement in regard to the habituation to auditory distractors. Testing whether the irrelevant sound effect habituates greatly helps to evaluate competing working memory models. According to the embedded-processes model (Cowan, 1995, 1999), the changing state effect is explained exclusively by habituation. Distraction occurs because novel and variable auditory distractors elicit an orienting response, which recruits attention away from the maintenance of the to-be-remembered target items. The orienting response habituates with repeated presentation of the same distractor, which serves as an attentional filter. If an incoming stimulus matches the neural model of a previously presented stimulus, the orienting response is attenuated. If discrepancies are detected, attentional orienting reoccurs. Steady state sequences cause only little interference because the system habituates quickly to repeated stimulation. The embedded-processes model predicts that auditory distraction should decrease when the same distractors have to be ignored repeatedly.

Within the duplex-mechanism account of auditory distraction (Hughes, Vachon & Jones, 2007), by contrast, the disruptive effect of changing state sounds is the result of a conflict between two seriation processes. The auditory information is preattentively segmented into auditory objects based on of mismatches between successive distractors. The order of the objects is automatically registered by an obligatory seriation process which interferes with the maintenance of the to-be-remembered order information. This automatic competition between irrelevant and relevant order cues (Hughes, Vachon & Jones, 2005; Vachon, Hughes & Jones, 2012) provides an alternative explanation of the changing state effect. This explanation is not based on attentional distraction and habituation. According to the duplex-mechanism account, attentional capture occurs when a distractor “violates the current set of heuristics (or algorithm) deployed by the perceptual system to integrate, preattentively, a succession of recent stimuli into the same coherent stream” (Hughes et al., 2007, p. 1059). Under these specific circumstances the encoding of the target items is impaired, which, in turn, disrupts serial recall. This mechanism, however, is not assumed to be involved in the disruption by changing state irrelevant sounds such as lists of words or regular speech. Thus, the changing state effect and the rare deviant effect are attributed to different mechanisms. The attention-based deviant effect is subject to habituation, whereas the changing state effect must not habituate because it does not involve attention (e.g., Jones, Hughes & Macken; Vachon et al., 2012).

Examining habituation of the irrelevant sound effect therefore allows to test the embedded-processes model against the duplex-mechanism account. Most notably, it is a crucial test of the embedded-processes model, in which the entire explanation of the changing state irrelevant sound effect is based on habituation. If the irrelevant sound effect would remain constant with repeated exposure, this would provide clear evidence against the embedded-processes model and strengthen the duplex-mechanism account (Hughes et al., 2007).

Previous results on whether the irrelevant sound effect habituates seem ambiguous at first sight. In some studies the disruptive effect of distractors on serial recall is diminished after repeated exposure (Banbury & Berry, 1997; Bell, Röer, Dentale & Buchner, 2012; Morris & Jones, 1990), whereas others reported no evidence of habituation (Ellermeier & Zimmer, 1997; Röer, Bell, Dentale & Buchner, 2011; Tremblay & Jones, 1998). A closer look reveals that habituation may occur with a greater probability when the auditory stimuli can be processed without concurrent working-memory load before they have to be ignored (see Bell et al., 2012 for an overview). In standard irrelevant sound experiments, in contrast, participants must cope with the taxing task of remembering an item sequence that exceeds working memory capacity while distractors are played. In this situation the disruptive effect of two alternating distractor words persisted even after 1960 repetitions of the to-be-ignored word pair (Röer et al., 2011). Thus, the state of knowledge before we ran the current series of experiments was (a) that habituation to irrelevant sound does not occur in standard irrelevant sound experiments, and (b) that habituation is confined to the special situation in which auditory stimuli are fully attended before they become distractors. The results reported here will change that.

In order to see why, we first had to realize that the literature on the habituation to auditory distractors can be viewed from a different perspective as well. When all studies examining habituation of the irrelevant sound effect are listed by the distractor material's complexity (Table 1), it is possible to conclude that habituation depends on the distractor material used. When complex distractor material was used, the disruptive effect typically decreased with repeated exposure (Banbury & Berry, 1997; Bell et al., 2012; Morris & Jones, 1990; but see Ellermeier & Zimmer, 1997). In contrast, most studies using simple distractor material found no evidence of habituation (Beaman & Röer, 2009; Jones, Macken & Mosdell, 1997; Röer et al., 2011; Tremblay & Jones, 1998, but see Bell et al., 2012). Thus, the chance to find habituation may increase as a function of the distractor material's acoustic complexity.

Two aspects seem to be of particular relevance. First, complex distractor material may capture more attention than simple distractor material, providing a greater potential for habituation. Specifically, complex sequences such as speech and melodies contain more changes in amplitude and frequency than sequences of monosyllabic words or alternating tones. Furthermore, in complex sequences, changes do not occur regularly, which should result in more pronounced distraction. By contrast, in a sequence of single words or tones the distractors are usually designed to be as similar as possible with respect to length, intonation, loudness, and timing. Second, the distractor stimuli were presented repeatedly within each trial in most studies (Beaman & Röer, 2009; Bell et al., 2012; Jones et al., 1997; Tremblay & Jones, 1998). For example, we (Röer et al., 2011) presented two alternating distractor words 24 times while participants saw the first sequence of target items. Therefore, habituation to within-sequence regularities may have occurred already within the first trial, decreasing the possibility to find a significant attenuation of interference when analyzing performance across trials. In other paradigms, it has been demonstrated that the disruptive potential of auditory distractors rapidly decreases after the first few repetitions of the auditory material (Elliott & Cowan, 2001; Shelton, Elliott, Eaves & Exner, 2009).

However, the interpretation of the evidence of habituation in experiments using complex to-be-ignored material is not straightforward either. Banbury and Berry (1997) used a prose memory task that required higher-level processing and therefore differs from the typical serial recall task. Bell et al. (2012) and Morris and Jones (1990) used a passive listening phase (see above). In fact, we know of only a single experiment in which trial-to-trial habituation to complex distractor material was examined in a typical irrelevant sound task. Ellermeier and Zimmer (1997) reported that the disruptive effect of Japanese speech remained constant after 50 trials of repetitive stimulation. Unfortunately, several aspects of the experimental design may have reduced the probability of finding habituation. First, in the statistical analysis each data point corresponded to a block of ten trials. Therefore, habituation may have occurred already within the first block (and may have been obscured in the blocked analysis). Second, the power to detect any remaining habituation was quite small given a total sample size of only $N = 25$. Third, speech trials, pink noise trials, and quiet trials were presented in a random order, leaving open the possibility that habituation was disrupted by the intermediate exposure to pink noise.

In sum, although our knowledge to date has been that habituation of the irrelevant sound effect is restricted to the special situation in which the auditory distractors can be processed without concurrent memory load (Bell et al., 2012), it is still possible that habituation of the irrelevant sound effect is more general, but has often remained undetected for the reasons outlined above. We therefore tested whether evidence of habituation to irrelevant speech may be observed when the experimental design allows for more sensitive measurements. First, we made sure that the critical statistical tests are sensitive, that is, that effects between $f = 0.11$ and $f = 0.15$ (i.e., small [$f = 0.1$] to medium [$f = 0.25$] effects, cf. Cohen, 1988) could be detected given reasonable error probabilities of $\alpha = \beta = .05$. Second, within-trial distractor repetitions were avoided. Third, complex distractors (spoken sentences and piano melodies) were used, which should facilitate detecting habituation. Fourth, we provided an extended training phase to reduce error variance caused by poor familiarization with the task.

According to the embedded-processes model the irrelevant sound effect should habituate independent of whether speech or non-speech distractors are used. The duplex-mechanism account, by contrast, predicts that habituation must not occur, again independent of the type of distractor material (e.g., Hughes et al., 2005, p. 747). A third account not yet mentioned, the feature model (Nairne, 1990; Neath, 1999, 2000), attributes the disruption by speech and non-speech sounds to different mechanisms. While short-term memory disruption by speech is partly caused by a feature overwriting of verbal features that should not habituate, disruption by non-speech sounds is explained by attentional disruption (Neath & Surprenant, 2001). Thus, the feature model predicts habituation to be more pronounced in the non-speech distractor condition, whereas the disruptive effect of speech should remain stable.

Experiment 1

Method

Participants

One hundred and thirteen Heinrich Heine University students (88 women, *M* of age = 23) participated for course credit or a small honorarium. They were fluent German speakers and reported normal hearing.

Materials

For each trial eight to-be-remembered digits were sampled randomly without replacement from the set {1, 2,..., 9}. The digits were presented consecutively at a rate of 1 per second (800 ms on, 200ms off) in 72 point Monaco font on a white background in the centre of a computer screen.

An exemplary distractor melody and text are shown in Figure 1. Eight piano melodies in common time with a length of four measures were generated with Apple's GarageBand music editing software. Each melody was transposed to C major and lasted 8s. Eight spoken texts (each from a different category) were taken from Experiment 4 of Bell et al. (2012). All texts were spoken by the same male speaker and lasted 8s. The melodies and texts were normalized to minimize amplitude differences amongst the stimulus materials. All sounds were presented binaurally at about 65 dB(A).

Procedure

Participants wore headphones with high-insulation hearing protection covers, which were plugged directly into an Apple iMac computer. Standard written instructions on the computer screen informed the participants that any sound would be task-irrelevant and should be ignored.

The training phase consisted of 16 quiet training trials to familiarize participants with the task. In the experimental phase (24 trials) participants completed eight trials in each of the three distractor conditions (quiet, melody, speech). The distractor conditions were presented in blocks the order of which was counterbalanced across participants (n = 19 for each order except for one with n = 18). Each trial started with the presentation of a red traffic light, which turned yellow and then green before the trial started. The to-be-ignored melody or spoken text or nothing was played while the to-be-remembered digits were presented. For each participant, one melody and one speech distractor were randomly selected from the pool of distractors to be played throughout the experiment. Thus, the same melody or spoken text was played in each trial of the melody or speech block, respectively. Immediately after each trial, participants recalled as many of the visually presented digits as possible. A series of question marks, one for each position, prompted the forward serial recall. Participants had to enter the digits in the order in which they had been presented, with each digit replacing one question mark. A digit at a particular serial position could be omitted by pressing a "don't know" button. Participants were required to recall the items in forward order, but were allowed to correct their responses by replacing a prior entry. Once the last question mark had been replaced, the next trial could be initiated by pressing the space bar. Feedback was given after each trial.

Design

A repeated measures design was used with distractor type (quiet, melody, speech) and ordinal trial position (1-8) as the independent variables and serial recall as the dependent variable. A progressive reduction of the auditory distractor's disruptive effects on recall over the eight trials of the distractor conditions (melody, speech) relative to the quiet condition would be evidence of habituation to the distractor sequences. Thus, the critical test of the habituation hypothesis is whether the difference between the melody and speech distractor conditions combined and the quiet condition becomes smaller as a function of ordinal trial position. Given a total sample size of $N = 113$, $\alpha = \beta = .05$, and an assumed average correlation of $\rho = .1$ among the levels of the variable capturing the difference between the distractor conditions combined and the quiet condition, habituation effects of size $f = 0.15$ (i.e., between small [$f = 0.1$] and medium [$f = 0.25$] effects, cf. Cohen, 1988) could be detected (Faul, Erdfelder, Lang & Buchner, 2007).

For all statistical analyses the level of α was .05. A multivariate approach was used for all within-subject comparisons. In the present application all multivariate test criteria correspond to the same exact *F* statistic, which is reported. Partial eta square (η_p^2) is reported as a measure of effect size.

Results

A response was scored as correct when the digits were reproduced in the serial position in which they had been presented. Figure 2 illustrates serial recall (averaged across the serial positions within each list) for the eight trials of the experimental phase, separately for each distractor condition. A 3×8-MANOVA yielded main effects of distractor type, $F(2,111) = 53.12$, $p < .001$, $\eta_p^2 = .49$, and of ordinal trial position, $F(7,106) = 3.88$, $p = .001$, $\eta_p^2 = .20$. There was also a significant interaction between distractor type and ordinal trial position, $F(14,99) = 2.26$, $p = .010$, $\eta_p^2 = .24$.

There was a typical irrelevant sound effect on serial recall: Orthogonal contrasts showed that more errors were made in the two distractor conditions combined relative to the quiet condition, $F(1,112) = 87.75$, $p < .001$, $\eta_p^2 = .44$. A common finding within the auditory distraction literature (when the acoustic variability is not controlled for) is greater disruption from irrelevant speech than from non-speech sounds (Buchner et al., 2008; LeCompte, Neely & Wilson, 1997). Consistent with those findings, speech caused more interference than melodies, $F(1,112) = 26.16$, $p < .001$, $\eta_p^2 = .19$.

Most importantly, there was a significant interaction between the linear contrast component of the ordinal trial position variable with the contrast of the distractor type variable comparing the two distractor conditions combined to the quiet condition, $F(1,112) = 9.61$, $p = .002$, $\eta_p^2 = .08$. This interaction reflects the progressively smaller performance gap between trials with and without auditory distractors at later trials, which is evidence of habituation. There was no such interaction when both distractor conditions were compared, $F(1,112) < 0.01$, $p = .952$, $\eta_p^2 < .01$, suggesting that speech and non-speech distractors were equally subject to habituation.

Discussion

The typical irrelevant sound effect on serial recall was observed: Compared to quiet participants made more errors when they had to ignore auditory distractors, with speech being more disruptive than melodies. More importantly, the disruptive effect of the auditory distractors decreased rapidly as a function of ordinal trial position, that is, after repeated presentation of the distractor sequence. In other words, Experiment 1 yielded clear evidence of habituation. This finding is remarkable given that a number of studies failed to find trial-based habituation (Ellermeier & Zimmer, 1997; Jones et al., 1997; Röer et al., 2011). One aspect that could explain this discrepancy is that different types of distractors were presented in blocks, whereas in previous attempts to examine habituation different types of distractors were presented in a random order (Ellermeier & Zimmer, 1997); in Experiment 1 of Jones et al. (1997) it was even ruled out that the same distractor types were repeated on successive trials. Therefore, it seemed important to examine whether the results of Experiment 1 can be replicated using the same approach as previous studies (i.e., a random order of distractor types).

Experiment 2

Method

Experiment 2 was identical to Experiment 1 with the following exceptions. One hundred and twenty-three Heinrich Heine University students (93 women) participated (*M* of age = 23). Distractor conditions were not presented in blocks. Instead, the order of the distractor conditions was determined randomly. Given a total sample size of $N = 123$ and all other elements of the power considerations identical to those of Experiment 1, habituation effects of size $f = 0.15$ (i.e., between small [$f = 0.1$] and medium [$f = 0.25$] effects, cf. Cohen, 1988) could be detected.

Results

Figure 3 shows serial recall across the eight trials of the experimental phase for each of the distractor conditions. A 3×8-MANOVA yielded main effects of distractor type, $F(2,121) = 63.91$, $p < .001$, $\eta_p^2 = .51$, and of ordinal trial position, $F(7,116) = 5.12$, $p < .001$, $\eta_p^2 = .23$. As in Experiment 1, there was a significant interaction between distractor type and ordinal trial position, $F(14,109) = 2.62$, $p = .003$, $\eta_p^2 = .25$.

Orthogonal contrasts showed that there was a typical irrelevant sound effect, $F(1,122) = 126.56$, $p < .001$, $\eta_p^2 = .51$. Again, speech sequences were more disruptive than melodies, $F(1,122) = 12.48$, $p = .001$, $\eta_p^2 = .09$. Most importantly, and parallel to Experiment 1, there was a significant interaction between the linear contrast component of the ordinal trial position variable with the contrast of the distractor type variable comparing the two distractor conditions combined to the quiet condition, $F(1,122) = 26.49$, $p < .001$, $\eta_p^2 = .18$. As in Experiment 1, this reflects the progressively smaller performance gap between trials with and without auditory distractors at later trials, which is evidence of habituation. No such interaction was found when both distractor conditions were compared with each other, $F(1,122) = 1.73$, $p = .191$, $\eta_p^2 = .01$.

Discussion

Experiment 2 replicates the finding of Experiment 1 that habituation occurs in the irrelevant sound paradigm. Moreover, it falsifies the assumption that a blocked design is necessary to obtain trial-based habituation. Thus, it seems that previous studies (Ellermeier & Zimmer, 1997; Jones et al., 1997) failed to find habituation not just because distractor conditions were presented in a random instead of a blocked order. We already elaborated on the possibility that in Ellermeier and Zimmer's (1997) study habituation to the auditory distractors may have occurred within the first block, which consisted of ten trials, as a consequence of which habituation could have been obscured in the blocked analysis. In Jones et al.'s (1997) Experiments 1 and 2 an attenuation to the the distractors' disruptive effects within the first trials may have been obscured as well by a blocked analysis with each block consisting of five trials. In their Experiment 1, in which trials were presented in a quasi-random order the average improvement in serial recall from the first to the second block was 3% in the quiet condition and 20% in the changing state condition. In Experiment 2, in which trials were presented in blocks, participants made more errors in the quiet condition (11%) from the first to the second block, while they again improved in the changing state condition (7%). Thus, the present results are fully consistent with previous results at a descriptive level. Given the results of Experiment 2, we incline to the conclusion that the main difference between the present study and previous studies is simply that the present experiments have more statistical power, and the trial-based (instead of block-based) analysis may be more sensitive to reveal habituation than the approaches used in previous studies.

As discussed above, the complexity of the stimulus material may play an important role, too. Apart from the difference in acoustic variability mentioned earlier, there is another difference between simple and complex distractor material. While the semantic content of a to-be-ignored sequence comprised of single words is negligible (e.g., "pier, hat, cow, nest, pin, boat, top", Jones et al., 1997), we used meaningful texts and harmonic, well-structured melodies as auditory distractors. Thus, one could speculate that a familiar speech pattern or a harmonic note progression may have facilitated the forming (and maintenance) of an internal representation of the to-be ignored sequences and with that, ultimately, habituation. It fits with this reasoning that the only study with complex distractor material that failed to find habituation (Ellermeier & Zimmer, 1997) used foreign speech distractors which none of the participants understood. In Experiment 3 we therefore compared two groups. The forward group had to ignore the speech sequences and melodies used in Experiments 1 and 2. For the backward group the distractors were reversed. Distractors in both playback directions feature the same amount of acoustic variability and should therefore produce the same amount of interference (the playback direction of a sequence typically has no effect on recall; e.g., Jones et al., 1990). If, by contrast, habituation occurs predominantly to semantic features of the to-be-ignored material, then habituation should be more pronounced in the forward than in the backward group.

Experiment 3

Method

Experiment 3 was identical to Experiment 1 with the following exceptions. Two hundred and four Heinrich Heine University students (103 in the forward group, 101 in the backward group; 154 women, *M* of age = 23) participated. The forward group represented an exact replication of Experiment 1. The backward group received the same auditory distractors as the forward group, but after they had been reversed. The reversed melodies obtained their melodic character with single tones clearly recognizable. By contrast, it was not possible to identify single words or even the meaning of the entire distractor speech in the backward speech condition.

A mixed design was used with playback direction (forward, backward) as between-subjects variable, and distractor type (quiet, melody, speech) and serial position (1-8) as within-subject variables. Given a total sample size of $N = 204$ and all other elements of the power considerations identical to those of Experiment 1, habituation effects of size $f = 0.11$ (i.e., essentially small [$f = 0.1$] effects, cf. Cohen, 1988) could be detected. In addition, we were interested in the interaction between the variable capturing the difference between the distractor conditions combined and the quiet condition on the one hand and the group variable on the other. For this interaction, effects of size $f(V) = 0.33$ could be detected (note that f and $f\,[V]$ differ in interpretation such that Cohen's effect size conventions cannot be used for $f\,[V]$; see Faul et al., 2007, for details).

Results

Figure 4 shows serial recall across the eight trials of the experimental phase for each of the distractor conditions in the forward (upper panel) and backward groups (lower panel). A 2×3×8-MANOVA yielded no effect of the playback direction, $F(1,202) = 0.05$, $p = .830$, $\eta_p^2 < .01$, but significant main effects of distractor type, $F(2,201) = 43.86$, $p < .001$, $\eta_p^2 = .30$ and of ordinal trial position, $F(7,196) = 6.29$, $p < .001$, $\eta_p^2 = .18$. Playback direction interacted neither with distractor type, $F(2,201) = 0.62$, $p = .539$, $\eta_p^2 = .01$, nor with ordinal trial position, $F(7,196) = 0.85$, $p = .551$, $\eta_p^2 = .03$. As in Experiments 1 and 2, there was a significant interaction between distractor type and ordinal trial position, $F(14,189) = 2.16$, $p = .011$, $\eta_p^2 = .14$, reflecting the progressive reduction of the auditory distractor's disruptive effect across the eight trials of the experiment. There was no three-way interaction, $F(14,189) = 0.32$, $p = .991$, $\eta_p^2 = .02$. In sum, playback direction had no effect at all. Specifically, it did not modulate habituation.

When the data from both playback direction groups were taken together, the results were identical to those of Experiments 1 and 2. Orthogonal contrasts revealed a typical irrelevant sound effect, $F(1,203) = 87.39$, $p < .001$, $\eta_p^2 = .30$, with speech sequences being more disruptive than melodies, $F(1,203) = 5.44$, $p = .021$, $\eta_p^2 = .03$. Most importantly, there was a significant interaction between the linear contrast component of the ordinal trial position variable with the contrast of the distractor type variable comparing the two distractor conditions combined to the quiet condition, $F(1,203) = 8.94$, $p = .003$, $\eta_p^2 = .04$. As in Experiments 1 and 2, this reflects the progressively smaller performance gap between trials with and without auditory distractors at later trials, which is evidence of habituation. There was no such interaction when both distractor conditions were compared with each other, $F(1,203) = 0.48$, $p = .490$, $\eta_p^2 < .01$.

When both groups were analyzed separately, there was only one difference to the results reported above: The difference between speech sequences and melodies failed to reach significance in both the forward, $F(1,102) = 1.79$, $p = .185$, $\eta_p^2 = .02$, and the backward group, $F(1,100) = 3.92$, $p = .050$, $\eta_p^2 = .04$. Apart from this, the results were identical. Again, there was a typical irrelevant sound effect on recall, $F(1,102) = 34.64$, $p < .001$, $\eta_p^2 = .25$ (forward group), $F(1,100) = 53.97$, $p < .001$, $\eta_p^2 = .35$ (backward group). Most importantly, there was a significant interaction between the linear contrast component of the ordinal trial position variable with the contrast of the distractor type variable comparing the two distractor conditions combined to the quiet condition, $F(1,102) = 4.76$, $p = .032$, $\eta_p^2 = .05$ (forward group), $F(1,100) = 4.15$, $p = .044$, $\eta_p^2 = .04$ (backward group), which is evidence of habituation. There was no such interaction when both distractor conditions were compared, $F(1,102) = 0.18$, $p = .894$, $\eta_p^2 < .01$, and, $F(1,100) = 0.95$, $p = .332$, $\eta_p^2 < .01$, respectively.

Discussion

The results obtained in Experiment 3 confirm previous findings showing that the semantic properties of the acoustic distractors have little, if any, influence on the disruption of serial recall (Buchner, Irmen & Erdfelder, 1996; Marsh, Hughes & Jones, 2009; Marsh & Jones, 2010; but see Röer, Bell & Buchner, in press). Given that playback direction had no effect whatsoever, two conclusions can be drawn. First, trial-based habituation seems to be a stable and replicable phenomenon when complex to-be-ignored material is used. Consistent with Experiments 1 and 2 the irrelevant speech effect was attenuated after eight trials of repeated stimulation. Second, habituation occurs to acoustic, not semantic features of the distractor material: In both the forward and backward group comparable habituation rates were observed.

Given that the lack of habituation to distractor speech in a similar design (cf. Ellermeier & Zimmer, 1997) was used as evidence against the involvement of attentional processes in the changing state irrelevant sound effect (Hughes et al., 2005), the present finding of habituation to speech with a presumably more sensitive procedure and much more statistical power must be counted as evidence in favor the involvement of attentional processes. Note, however, that the duplex-mechanism account allows for attentional capture by distractors that violate "the current set of heuristics (or algorithm) deployed by the perceptual system to integrate, preattentively, a succession of recent stimuli into the same coherent stream" (Hughes et al., 2007, p. 1059). Such attention-capturing violations, however, only interfere with the encoding of the item list (Hughes et al., 2005), while automatic order interference is assumed to be detrimental at any stage of processing. Under the premise that the irrelevant sound effect in general consists both of attentional capture (which habituates) and automatic order interference (which is unaffected by habituation and explains the residual interference after eight repetitions of the distractor material), the duplex-mechanism account predicts that habituation must not occur when distractors are played only during retention. This prediction was tested in Experiment 4 which was identical to Experiment 1 with the exception that the auditory distractors were only played during a retention interval.

Experiment 4

Method

Experiment 4 was identical to Experiment 1 with the following exceptions. One hundred and eighteen Heinrich Heine University students (82 women) participated (*M* of age = 24). There was a retention interval of eight seconds between the presentation of the item list and recall. The target items were presented in silence in each distractor condition (quiet, melody, speech). Distractor sounds were only played in the retention interval after the last item had been presented visually.

Given a total sample size of N = 118 and all other elements of the power considerations identical to those of Experiment 1, habituation effects of size f = 0.15 (i.e., between small [f = 0.1] and medium [f = 0.25] effects, cf. Cohen, 1988) could be detected.

Results

Figure 5 shows serial recall across the eight trials of the experimental phase for each of the distractor conditions. A 3×8-MANOVA yielded main effects of distractor type, $F(2,116) = 58.01$, $p < .001$, $\eta_p^2 = .50$, and of ordinal trial position, $F(7,111) = 9.59$, $p < .001$, $\eta_p^2 = .38$. As in Experiments 1, 2, and 3, there was a significant interaction between distractor type and ordinal trial position, $F(14,104) = 1.91$, $p = .033$, $\eta_p^2 = .21$.

There was an irrelevant sound effect, $F(1,117) = 115.93$, $p < .001$, $\eta_p^2 = .50$, with speech sequences again being more disruptive than the melodies, $F(1,122) = 9.61$, $p = .002$, $\eta_p^2 = .08$. Most importantly, there was a significant interaction between the linear contrast component of the ordinal trial position variable with the contrast of the distractor type variable comparing the two distractor conditions combined to the quiet condition, $F(1,117) = 10.13$, $p = .002$, $\eta_p^2 = .08$. There was no such interaction when both distractor conditions were compared with each other, $F(1,117) = 0.52$, $p = .472$, $\eta_p^2 < .01$. Despite the fact that the distractors were only played after the presentation of the item list in Experiment 4, the results mirror those of Experiments 1, 2, and 3.

Discussion

Consistent with previous observations (Buchner et al., 2008; Buchner et al., 2004; Miles et al., 1991), Experiment 4 confirmed that irrelevant sound that is played in a retention interval can be as disruptive as sound that is played simultaneously to item presentation. In fact, with $\eta_p^2 = .50$ the size of the irrelevant sound effect was about as large as the irrelevant sound effects in Experiments 1, 2, and 3 with η_p^2 = .44, .51, and .30, respectively. Most importantly, habituation to melodies and speech was observed even though the auditory distractors were only played after the encoding of the item list was completed, showing that the disruptive effects of attention demanding sound characteristics are not limited to the encoding stage as suggested by the findings of Hughes et al. (2005), but can indeed disrupt the retention of target items, too. With η_p^2= .08 the size of the habituation effect was about as large as the habituation effects in Experiments 1, 2, and 3 with η_p^2 = .08, .18, and .04, respectively.

At first sight, this evidence of attentional processes during retention appears to stand in contrast to the results of Hughes et al. (2005) that a single delayed distractor in an otherwise regularly timed distractor sequence disrupted serial recall during presentation, but not during retention of the item list. In the attempt to explain this discrepancy, one aspect seems to be particularly relevant. Parallel to our Experiments 1 and 4, Hughes et al. (2005) manipulated the presentation time of the distractors (encoding vs. retention) across two experiments. In their Experiment 1 in which the distractors occurred during encoding, the changing state effect was large (η_p^2 = .68). The effect of the single delayed distractor was much smaller (η_p^2 = .23) which is to be expected. Unfortunately, in their Experiment 2 in which the distractors occurred during retention, the changing state effect was already substantially smaller (η_p^2 = .37) than in Experiment 1 such that the expected effect of the single delayed distractor also must have been considerably smaller than in Experiment 1. Combined with the relatively small sample size (N = 29) their Experiment 2 simply may not have had enough statistical power to allow for a reliable detection of the presumably quite small effect of a single delayed distractor. Further, in Experiment 2 the delayed distractor was presented relatively late such that participants could take advantage of the added retention interval by rehearsing the previously presented target items 9 s instead of 3 s (as in their Experiment 1) before the auditory deviant appeared, rendering the representation of the to-be-remembered items less vulnerable to distraction, thus further reducing the expected effect of the delayed deviant. Considering these reasons for Hughes et al.'s (2005) failure to find a deviant effect during retention, these findings do not contradict the evidence of the present Experiment 4 showing that attentional processes are involved in item retention.

General Discussion

All experiments yielded clear and consistent evidence of habituation of the irrelevant sound effect. The disruptive effect of the distractor sequences was markedly attenuated after repeated exposure both when the auditory conditions were presented in blocks and in random order. Forward and backward distractor sequences were equally disruptive, showing that habituation was unaffected by the semantic features of the distractors. There was also clear evidence of habituation when the auditory distractors were only played in a retention interval after encoding was completed.

The average improvement in serial recall from the first to the eighth trial was 9% (10%, 9%, 9%, and 12% in Experiments 1, 2, 3, and 4, respectively) for the melodies, and 10% (10%, 12%, 8%, and 15%) for the speech sequences. With 1% improvement in the quiet condition (2%, 0%, 2%, and 3%), in contrast, there was no evidence that participants generally improved during the course of an experiment. This difference between the distractor conditions on the one hand and the quiet condition on the other is remarkable insofar as in a number of recent publications, including our own (Röer et al., 2011), the prevailing view was that the irrelevant sound effect is not subject to habituation (e.g., Klatte, Lachmann, Schlittmeier & Hellbrück, 2010; Perham & Vizard, 2011; Sörqvist, 2010; Vachon et al., 2012). The present findings show that this conclusion may have been premature. Remarkably, the largest improvement occurred within the first four to five trials. This may be the main reason why previous attempts to detect trial-based habituation failed. Ellermeier and Zimmer (1997) compared performance between blocks of ten trials, Jones et al. (1997) averaged over five trials. This may have masked important changes occurring in the first few trials, thus reducing the probability of detecting habituation.

One of the assumptions explicated above is that the complexity of the to-be-ignored material may play a role in that habituation to more complex material takes longer and is thus easier to observe in the typical serial recall task than habituation to very simple auditory distractors such as two alternating words. In a series of experiments similar to those reported here, we used two alternating monosyllabic distractor words as auditory distractors (Röer et al., 2011) and found no evidence of habituation within the first ten trials. Given the present results, we regard our earlier conclusion that habituation had not occurred as premature. The to-be-ignored distractor words were repeated 24 times during each trial, so that habituation to unspecific and specific distractor features may have occurred already during the first few distractor presentations within the first trial. Aggregating over 24 repetitions probably masked the habituation that occurred already within the first trial, thereby decreasing the likelihood to find evidence of habituation across trials.

In summary, at least four aspects seem relevant when trial-based habituation to auditory distractors is to be observed. First, only a moderate amount of trials is needed to find an attenuation of the irrelevant sound effect. Rapid habituation to task-irrelevant distractors is, for instance, commonly observed with deviating stimuli (Vachon et al., 2012) or when a different primary task is used (e.g., solving arithmetic problems, Waters, McDonald & Koresko, 1977, see also Elliott & Cowan, 2011, Shelton et al., 2009). Second, complex stimulus material seems better suited than simple material such as sequences of single words that are often very homogenous with respect to a number of distractor features (e.g., length, intonation, timing) to which habituation might occur rapidly within the first trial, which, in turn, decreases the probability of detecting evidence of habituation across trials. Third, although we have not tested this directly, an extended training phase may help to reduce error variance caused by poor familiarization with the serial recall task—in particular within the first few trials, which are most important for examining short-term habituation. Fourth, large samples seem necessary to make sure that the statistical power is sufficient to find habituation effects in the irrelevant sound paradigm. On a related note, the pre-exposure to the later to-be-ignored distractor material may foster habituation, but habituation is not, as previously assumed, restricted to such a design (Bell et al., 2012). Further, it has been demonstrated in previous studies that the rate of habituation seems to depend on the working memory capacity in some experimental designs (Sörqvist et al., 2012). Against the backdrop of previous findings showing that the irrelevant speech effect is unrelated to working memory capacity (Beaman, 2004; Sörqvist, 2010), it remains an open question for future research whether the same applies to habituation of the irrelevant sound effect.

Most previous evidence led to the conclusion that habituation to auditory distractors does not occur, and these finding had a large impact on theoretical explanations of the irrelevant sound effect. Therefore, the theoretical positions based on those previous findings must be revised to take the present findings into account. Trial-based habituation of the irrelevant sound effect is largely compatible with the embedded-processes model (Cowan, 1995, 1999), in which the auditory distractors are assumed to elicit orienting responses that draw attention away from the rehearsal of the target items. The attenuation of the distractor's disruptive effects corresponds to the model's assumption that after repeated exposure a neural model is formed and orienting habituates. Given the results presented here, the absence of habituation in the irrelevant sound paradigm can no longer be used as an argument against an involvement of attentional processes in the irrelevant sound effect. However, even if habituation occurred very quickly and remained obscured by averaging over too many distractor repetitions (e.g., Röer et al., 2011) the question remains why there seems to be no complete habituation to auditory distractors. For instance, a notable irrelevant speech effect was observed even after as many as 1,960 distractor repetitions in Röer et al.'s Experiments 2 and 3. This is probably due to the nature of the task. In a typical irrelevant sound experiment the distractors are not attended and working memory is concurrently loaded. Even the onsets of repeated distractors may recruit some processing because their representations have to be compared to existing neural models before an attention switch to the auditory modality is denied. It seems plausible to assume that this very basic "call for attention" process leads to some degree of interference even when a full attention switch to the auditory modality is not elicited (Campbell, Winkler, Kujala & Näätänen, 2003). Therefore, habituation may never be complete in a very strong sense, which would enable the organism to devote minimal amounts of processing resources even to distracting events that had been irrelevant for a long time.

Further, the present results differ from what the feature model would predict (Nairne, 1990; Neath, 1999, 2000), which claims that short-term memory disruption by speech sounds is primarily due to automatic feature overwriting, whereas disruption by non-speech sounds is exclusively explained by an attentional mechanism. The feature model thus would be most compatible with habituation being particularly pronounced for the non-verbal distractors (the melodies), which was not the case. Nevertheless, the attentional parameter used in the model is not restricted to non-speech sounds, but is also thought to contribute to the disruption of speech distractors. The feature model could be modified to take the present results into account by postulating that short-term memory disruption by speech sounds is not primarily due to automatic feature overwriting but to attentional distraction instead. This would consistent with the model's assumption that the disruption of variable distractor sequences (in contrast to repetitive sequences) is largely due to attentional distraction. At the same time, this modification seems somewhat unattractive because it would eliminate the core of the model.

The observed trial-based habituation of the irrelevant sound effect is also inconsistent with the duplex-mechanism account (Hughes et al., 2005, 2007; Vachon et al., 2012), according to which the changing state irrelevant sound effect is the result of an automatic competition for action between irrelevant and relevant order cues that is explicitly assumed not to habituate (Vachon et al., 2012). In principle the reduced disruption after the repeated presentation of the same auditory distractors simultaneously to the presentation of the target items (Experiments 1, 2, and 3) might be explained with habituation of the duplex-mechanism account's attentional capture component of auditory distraction. In the duplex account, attentional capture occurs when a distractor "violates the current set of heuristics (or algorithm) deployed by the perceptual system to integrate, preattentively, a succession of recent stimuli into the same coherent stream" (Hughes et al., 2007; see also Vachon et al., 2012). The problem with this attentional-capture explanation is that it seems quite implausible that the spoken sentences and the melodies violated perceptual heuristics at any level (e.g., that of good continuation).Moreover, such an explanation would also be difficult to reconcile with the fact that the absence of habituation to distractor speech similar to that used in the present experiments has been repeatedly brought forward as evidence against the involvement of attentional processes in the explanation of the changing state irrelevant sound effect (e.g., Hughes et al., 2005). Furthermore, if such a violation was responsible for the observed effects, it should be limited to the encoding of the target items and not affect their maintenance in working memory, and the results of Experiment 4 disconfirm this assumption.

It may, however, be possible to modify the duplex-mechanism account to accommodate the present results. First, it should be acknowledged that variable and complex background sounds such as normal and reversed speech or melodies are capable of capturing attention. In doing so, the mechanism causing the attentional capture would have to be more flexible, so that it responds to unpredictability in a more general sense. Second, the duplex-mechanism account currently includes the assumption that attentional capture effects are limited to encoding,. To account for the present results, the model would therefore have to be revised to allow for attentional capture to be a general feature of the irrelevant sound effect, which interferes with the maintenance of the items in working memory. This explanation of the present results is certainly post-hoc and less elegant than attributing auditory distraction either solely to attentional disruption or to automatic interference. However, such an approach may have the potential to integrate conflicting findings in the irrelevant sound literature. An intriguing possibility is that habituation may help to disentangle attentional and non-attentional mechanisms of the phenomenon. For instance, as mentioned above, habituation of the irrelevant sound effect is rarely complete (Banbury & Berry, 1997; Beaman & Röer, 2009; Bell et al., 2012; Ellermeier & Zimmer, 1997; Jones et al., 1997; Morris & Jones, 1990; Röer et al., 2011; Tremblay & Jones, 1998). There is usually some residual interference even after considerable exposure to the auditory distractors. Likewise, in the experiments reported here, melodies and speech sequences caused a reduced, but still significant irrelevant sound effect after eight repetitions (Experiment 1: $t(112) = 3.03$, $p = .003$, $\eta_p^2 = .08$; $t(112) = 4.62$, $p < .001$, $\eta_p^2 = .16$; Experiment 2: $t(122) = 2.80$, $p = .006$, $\eta_p^2 = .06$; $t(122) = 5.26$, $p = .025$, $\eta_p^2 = .18$; Experiment 3: $t(102) = 2.23$, $p = .028$, $\eta_p^2 = .05$; $t(102) = 2.63$, $p = .010$, $\eta_p^2 = .06$ [forward group]; $t(100) = 3.49$, $p = .001$, $\eta_p^2 = .11$; $t(100) = 3.62$, $p < .001$, $\eta_p^2 = .12$ [backward group]; Experiment 4: $t(117) = 2.00$, $p = .048$, $\eta_p^2 = .03$; $t(117) = 2.99$, $p = .003$, $\eta_p^2 = .07$). It is possible that this interference may represent a form of auditory distraction that cannot be attributed to attentional capture, which would fit quite nicely with the general idea behind the duplex-mechanism account.

All in all, the present experiments show that habituation to complex auditory distractors occurs even when the distractors have to be ignored during the encoding and maintenance of short lists of items. This is only consistent with working memory models that allow for attentional capture by auditory distractors to play a role in the conceptualization of the changing state irrelevant sound effect. In closing, the observed pattern of results seems quite plausible from a functional perspective, too. Ignoring distractors completely would be dysfunctional because it would prevent the processing of potentially important, but previously irrelevant information in working memory. Habituation to auditory distractors may therefore serve as a simple adaptive process to reduce the costs that come with the auditory system's openness and distractibility.

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Table 1

An Overview of Studies on the Habituation to Irrelevant Sound

Study	Experiments	Items	Distractors	Habituation
Experiments using simple to-be-ignored material				
Beaman & Röer (2009)	1	Words	Single tones	No
	2	Words	Single words	No
Bell et al. (2012)	1-3, 5	Digits	Single words	Yes
Jones et al. (1997)	1-3	Letters	Single words	No
Röer et al. (2011)	1-3	Digits	Single words	No
Tremblay & Jones (1998)	3	Letters	Single words	No
Experiments using complex to-be-ignored material				
Banbury & Berry (1997)	1	Prose	Speech	Yes
	2, 3	Prose	Speech and office noise	Yes
Bell et al. (2012)	4	Digits	Speech	Yes
Ellermeier & Zimmer (1997)	1	Digits	Speech	No
Morris & Jones (1990)	1	Letters	Speech	Yes

Figure Captions

Figure 1: Examples for a to-be-ignored melody and text. Distractor texts were taken from Bell et al. (2012). The translation for the exemplary text reads as follows: "Tuesday mostly sunny with scattered showers. A weak to moderate northeasterly wind is blowing."

Figure 2: Recall performance across the eight trials as a function of distractor condition (quiet, melody, speech). The ordinal trial position corresponds to the total number of times in which the same distractor sequence has been played in the course of the experiment.

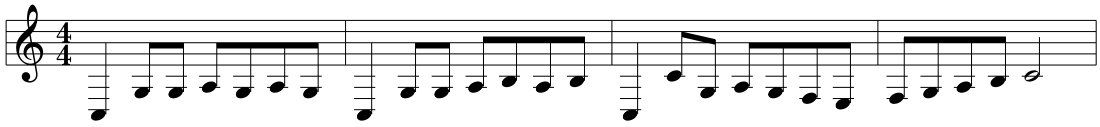
Figure 3: Recall performance across the eight trials as a function of distractor condition (quiet, melody, speech). The ordinal trial position corresponds to the total number of times in which the same distractor sequence has been played in the course of the experiment.

Figure 4: Recall performance across the eight trials as a function of distractor condition (quiet, melody, speech) when the distractor sequences were either played forward (upper panel) or backward (lower panel). The ordinal trial position corresponds to the total number of times in which the same distractor sequence has been played in the course of the experiment.

Figure 5: Recall performance across the eight trials as a function of distractor condition (quiet, melody, speech). The ordinal trial position corresponds to the total number of times in which the same distractor sequence has been played in the course of the experiment.

Figure 1

Melody



Speech

Am Dienstag überwiegend sonnig, nur vereinzelt sind Schauer möglich.
Es weht ein schwacher bis mäßiger Nordostwind.

Figure 2

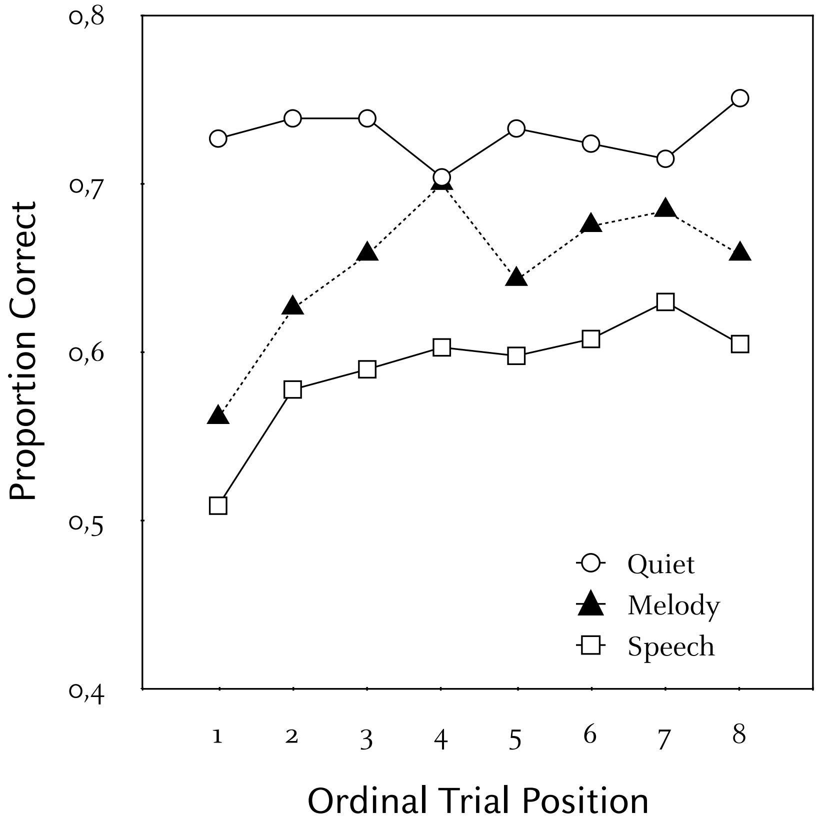

0,8
0,7
0,6
0,5
0,4
Proportion Correct
1
2
3
4
5
6
7
8
Ordinal Trial Position
Quiet
Melody
Speech

Figure 3

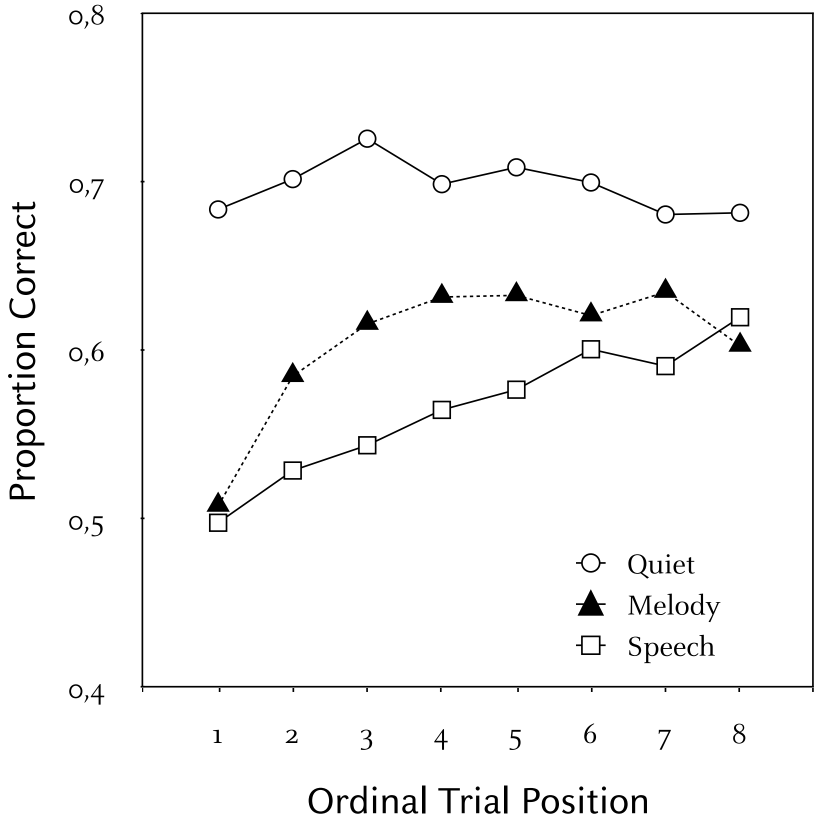

0,8
0,7
0,6
0,5
0,4
Proportion Correct
1
2
3
4
5
6
7
8
Ordinal Trial Position
Quiet
Melody
Speech

Figure 4

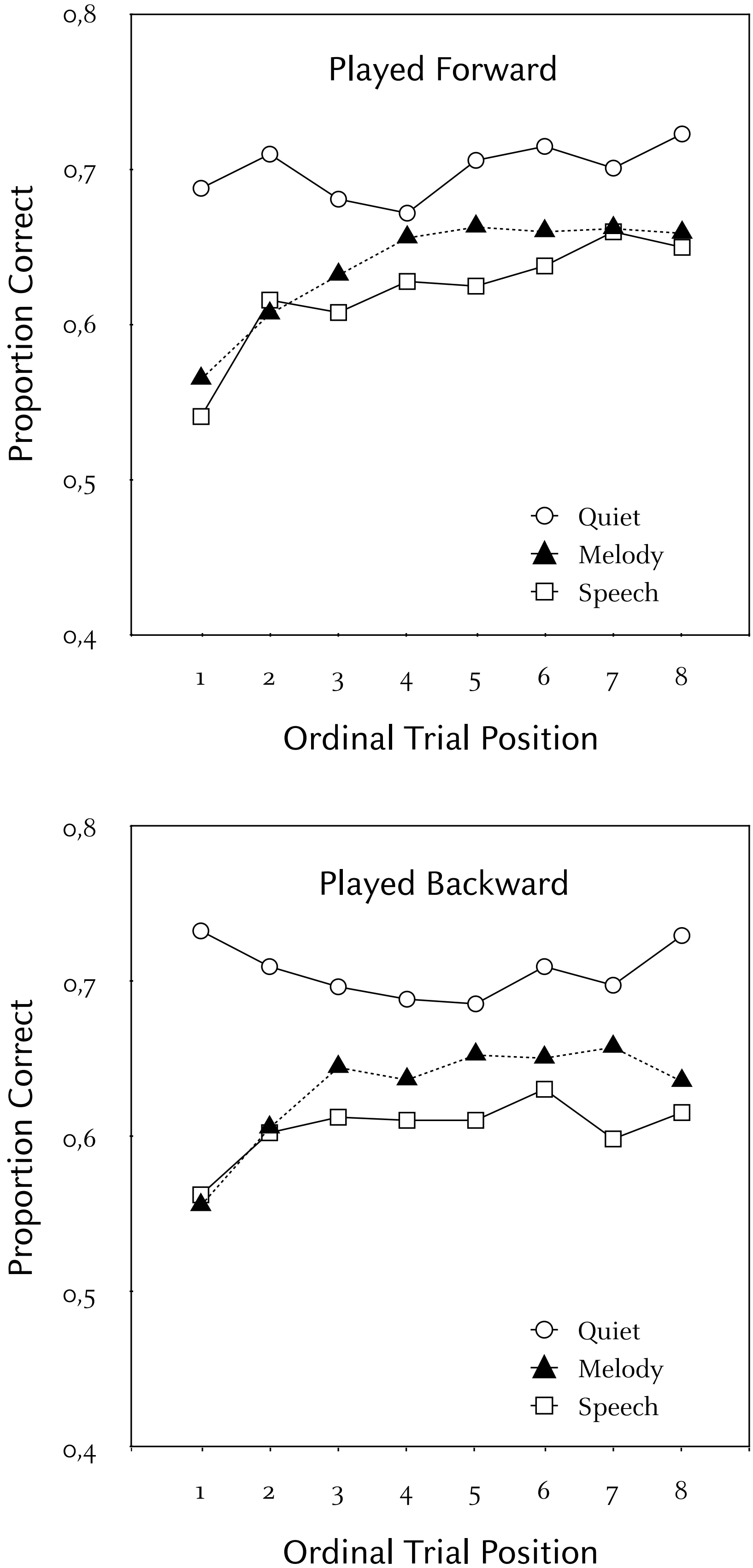
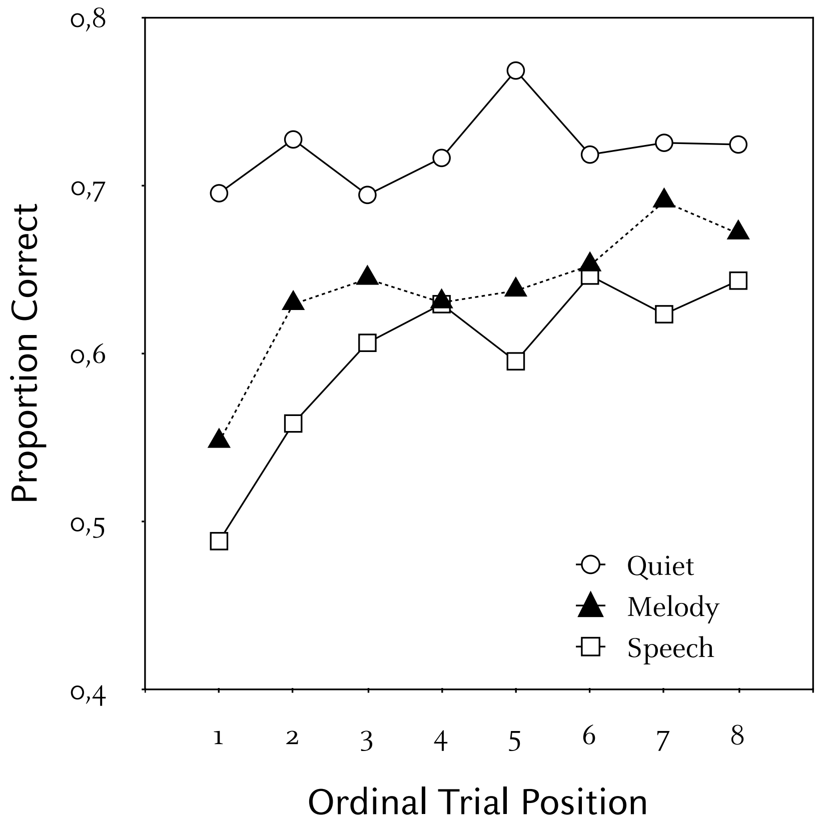

Played Forward
Proportion Correct
0,8
0,7
0,6
0,5
0,4
Quiet
Melody
Speech
1 2 3 4 5 6 7 8
Ordinal Trial Position
Played Backward
Proportion Correct
0,8
0,7
0,6
0,5
0,4
Quiet
Melody
Speech
1 2 3 4 5 6 7 8
Ordinal Trial Position

Figure 5


0,8
0,7
0,6
0,5
0,4
Proportion Correct
1
2
3
4
5
6
7
8
Ordinal Trial Position
Quiet
Melody
Speech