The effect of cognitive control on different types of auditory distraction: A preregistered study

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Abstract

Deviant as well as changing auditory distractors interfere with short-term memory. According to the duplex model of auditory distraction, the deviation effect is caused by a shift of attention while the changing-state effect is due to obligatory order processing. This theory predicts that foreknowledge should reduce the deviation effect, but should have no effect on the changing-state effect. We compared the effect of foreknowledge on the two phenomena directly within the same experiment. In a pilot study, specific foreknowledge was impotent in reducing either the changing-state effect or the deviation effect, but reduced disruption by sentential speech, suggesting that the effects of foreknowledge on auditory distraction may increase with the complexity of the stimulus material. Given the unexpected nature of this finding, we tested whether the same finding would be obtained in (a) a direct preregistered replication in Germany and (b) an additional replication with translated stimulus materials in Sweden.

Keywords: Attentional Capture; Working Memory; Cross-Modal Distraction; Top-Down Control; Interference Control

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Running Head: Cognitive Control of Auditory Distraction

Cognitive performance often suffers when auditory distractors have to be ignored. The serial-recall paradigm—in which short lists of digits have to be remembered immediately after their presentation or after a short retention interval—is a standard paradigm for examining the effects of auditory distraction on cognitive performance (Bell, Dentale, Buchner, & Mayr, 2010; Campbell, Beaman, & Berry, 2002; Colle & Welsh, 1976; Hughes, Vachon, & Jones, 2005; Jones & Macken, 1995; Lange, 2005; Schlittmeier, Weißgerber, Kerber, Fastl, & Hellbrück, 2012; Sörqvist, 2010). Auditory distraction in this paradigm is mainly caused by changes in the to-be-ignored auditory modality (Ellermeier & Zimmer, 2014) and occurs independently of sound characteristics that intuitively appear relevant at first such as the absolute sound level (Ellermeier & Hellbrück, 1998). Steady-state distractor sequences consisting of repetitions of the same distractor item (e.g., AAAAAAAA) may cause some distraction (LeCompte, 1995), but the disruption of short-term memory is more pronounced when the distractor sequences comprise auditory changes. Two different phenomena are often contrasted with each other. The deviation effect (Hughes et al., 2005; Lange, 2005) refers to the observation that repetitive steady-state sequences with auditory deviations (e.g., AAAABAAA) cause more distraction than steady-state sequences without such deviations. The changing-state effect (Bell et al., 2010; Campbell et al., 2002; Jones & Macken, 1995) refers to the observation that changing-state sequences with changes between consecutive distractors (e.g., ABCDEFG) disrupt short-term memory more than steady-state sequences consisting of distractor repetitions.

On the face of it, the deviation effect and the changing-state effect seem to be quite similar: Both effects show that abrupt changes in the auditory modality interfere with short-term memory. Therefore, it seems parsimonious to attribute both phenomena to the same underlying mechanism. Such a unitary explanation is offered by the attentional account of auditory distraction (Cowan, 1995), which attributes both effects to attentional capture. When deviations or changes in the auditory modality capture attention, the focus of attention is no longer fully available for rehearsal, and short-term memory performance suffers. At first glance, a unitary explanation seems to provide a simple and satisfactory explanation for both phenomena.

However, it has been argued that the two phenomena require different theoretical explanations because they can be empirically dissociated. The duplex model of auditory distraction (Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013; Hughes et al., 2005; Hughes, Vachon, & Jones, 2007) postulates that the deviation effect and the changing-state effect are caused by entirely different mechanisms: While the deviation effect is attributed to a withdrawal of attention from the visual encoding of the to-be remembered items, the changing-state effect is attributed instead to the obligatory processing of the order of the to-be ignored changing-state sequences, which is assumed to interfere with the short-term maintenance of the order of to-be-remembered information. At present, the duplex model is the most widely used framework for interpreting auditory distraction effects (Elliott et al., 2016; Marsh, Röer, Bell, & Buchner, 2014; Sörqvist, 2010).

An obvious advantage of the unitary attentional account over the duplex account is that it makes fewer and less complex theoretical assumptions. It is uncontroversial that the simpler explanation should be preferred based on the criterion of parsimony alone (Hughes et al., 2007). However, if dissociations between the deviation effect and the changing-state effect can be demonstrated at an empirical level, the unitary explanation may have to be replaced by a more complex explanation that can incorporate these findings. Therefore, the acceptance of the duplex model crucially depends on the persuasiveness of the empirical evidence showing that the two effects can be dissociated from each other (for a review, see Hughes, 2014). To evaluate the duplex model, it is necessary to assess whether these dissociations convincingly falsify a unitary account of auditory distraction.

Here, we focus on the assumption that the deviation effect is due to attentional processes that can be voluntarily controlled while the changing-state effect is due to automatic processes that are obligatory and cannot be voluntarily controlled (Hughes et al., 2013). Both the changing-state effect and the deviation effect can be ascribed to involuntary, stimulus-driven, bottom-up processing because participants are instructed to focus only on the visual primary task and to ignore the auditory distractors. However, this does not necessarily mean that the processing of distractor information is entirely inaccessible to cognitive control because it seems conceivable that the orienting to auditory distractors can be voluntarily suppressed to some extent. According to the duplex model (Hughes et al., 2013), it should be easier to control the focus of attention and to suppress involuntary attention switches to the auditory modality than to exert control over the obligatory and comparatively inaccessible processing of order that is assumed to underlie the changing-state effect. Given that the deviation effect can be conceptualized in terms of a violation of expectations (Nöstl, Marsh, & Sörqvist, 2012; Röer, Bell, & Buchner, 2014b; Vachon, Hughes, & Jones, 2012), performance in the deviation condition may benefit from foreknowledge about imminent distractor sequences (Horváth & Bendixen, 2012; Shelton, Elliott, Eaves, & Exner, 2009; Sussman, Winkler, & Schröger, 2003), whereas the obligatory order processing underlying the changing-state effect should be unaffected by foreknowledge. Therefore, the duplex model is supported by the finding that a warning about the nature of the imminent auditory sequence reduced the deviation effect, but did not modulate the changing-state effect (Hughes et al., 2013): In an experiment with $N = 24$ participants, an unspecific warning (the mere information that a deviation sequence was about to be presented) significantly reduced the deviation effect, but similar warnings about changing-state sequences had no effect in a separate experiment with $N = 31$ participants. At first glance, these findings provide convincing evidence for the existence of dissociable auditory-distraction mechanisms that are differentially amenable to top-down control.

This interpretation, however, is complicated by two factors. First, the duplex model predicts that there "are fundamental differences between the changing-state effect and aspecific attentional capture" (Hughes, 2014, p. 33). However, this "distinction at the heart of the duplex-mechanism account" (Hughes, 2014, p. 32) is rarely tested directly within a single experiment. Instead, almost all evidence in favor of a dissociation between the deviation effect and the changing-state effect relies on comparisons across studies. This implies that it is necessary to interpret a significant foreknowledge effect in one experiment and a nonsignificant foreknowledge effect in another experiment as evidence for a dissociation between the two phenomena. Such an interpretation, however, is problematic (Gelman & Stern, 2006). To illustrate, it seems possible that an effect just fails to reach statistical significance in one experiment (e.g., $p = .06$), and just obtains statistical significance in another experiment (e.g., $p = .04$). Obviously, such a pattern should not be taken as clear evidence for a dissociation. To make a more valid comparison between the two phenomena, it is necessary to contrast the changing-state condition and the deviation condition directly within a single experiment. Specifically, foreknowledge should improve performance in the deviation condition, but should have no influence on the changing-state condition. This hypothesis translates into an interaction between foreknowledge (present vs. absent) and distractor condition (changing-state vs. deviation). To our knowledge, it has not been empirically tested whether such an interaction exists. Currently the conclusions rely on methodologically problematic comparisons between experiments that are not backed up by direct statistical tests. This is unfortunate given that such evidence would be crucial to meaningfully evaluate the hypothesis that deviation distraction and changing-state distraction are differentially amenable to cognitive control.

To show that this is not merely a theoretical issue, let us consider another supposed dissociation between the changing-state effect and the deviation effect. According to Sörqvist (2010), "a large body of evidence has demonstrated habituation toward the disruptive effects of deviating sounds on task performance (…) but people seem unable to habituate to the effects of changing-state sound sequences on serial recall" (p. 651). However, the literature on habituation is generally quite inconsistent, with some studies showing habituation of changing-state distraction (Bell, Röer, Dentale, & Buchner, 2012; Morris & Jones, 1990; Pelletier, Hodgetts, Lafleur, Vincent, & Tremblay, 2016; Röer, Bell, & Buchner, 2014a), and others failing to find habituation (Ellermeier & Zimmer, 1997; Jones, Macken, & Mosdell, 1997; Röer, Bell, Dentale, & Buchner, 2011). Habituation of the deviation effect is also not reliably obtained (Hughes et al., 2005). The most direct evidence was obtained in a study by Röer, Bell, Marsh, and Buchner (2015), in which the changing-state effect and the deviation effect were compared in a repeated-measures design. At first glance, the results seem to provide support for a dissociation because the deviation effect significantly decreased over the course of the experiment ($p = .02$)—which provides evidence of habituation—while the reduction of the changing-state effect over trials failed to reach significance ($p = .05$). However, when the changing-state condition and the deviation condition were directly compared, there was no evidence that performance in these two conditions showed a differential improvement over the course of the experiment ($\eta_p^2 < .01$) despite a large sample size of $N = 258$ that guaranteed a high statistical power to detect a dissociation if it existed. This finding illustrates that being able to perform a direct comparison between the deviation condition and the changing-state condition is important for the interpretation of the results. Specifically, the two effects may show a differential pattern of significance when examined in isolation, but this cannot be taken as conclusive evidence for a dissociation (Gelman & Stern, 2006).

Another problem is that the evidence for differential foreknowledge effects on changing-state and deviation distraction is not as clear as it may appear at first. Röer, Bell, and Buchner (2015) showed that the distraction by complex changing-state sequences (coherent sentences) was significantly reduced by specific foreknowledge (transcripts of the imminent distractor speech), but not by unspecific foreknowledge. In a separate experiment, distraction by simple changing-state sequences (consisting of eight one-syllable words) was not significantly affected by specific foreknowledge, but it was descriptively reduced in the with-foreknowledge condition ($\eta_p^2 = .22$) in comparison to the without-foreknowledge condition ($\eta_p^2 = .30$). These findings cast some doubt on the alleged dissociation between the deviation effect and the changing-state effect.

To sum up, a differential effect of foreknowledge on the changing-state effect and the deviation effect has not yet been conclusively demonstrated. This hypothesis can only be properly evaluated when both changing-state and deviation sequences are presented within a single study, which allows for a direct comparison of the foreknowledge effect between these two conditions. In the present study, we presented steady-state, deviation, simple changing-state, and complex changing-state distractor sequences. We used speech distractors and specific warnings—for which large distraction and foreknowledge effects can be expected—to provide optimal conditions for testing the opposing predictions of the working memory models. The duplex model makes the clear prediction that foreknowledge should improve performance in the deviation condition, but it should not affect any of the changing-state conditions. Translated into a statistical hypothesis, this should result in a significant interaction between the foreknowledge variable (with vs. without foreknowledge) and the distractor-type variable (deviation vs. changing state). The unitary attentional account predicts that performance in all conditions should benefit from foreknowledge. However, it allows for an interaction because the usefulness of foreknowledge may vary depending on the degree to which the distractors cause a performance decrement. Steady-state distractors, for example, are highly predictable even without a specific warning about the upcoming steady-state sequence. They interfere less with serial recall than deviation or changing-state distractors. If there is less distraction, there is less potential for foreknowledge to benefit performance. Therefore, this condition served as the standard control condition in previous studies (Hughes et al., 2013; Röer, Bell,

& Buchner, 2015) and in the present study as well. If the foreknowledge manipulation is effective, it should have more influence on conditions which cause large distraction effects simply because there is more opportunity for a reduction of distraction and more room for improvement. Interestingly, this line of reasoning results in a prediction that is directly opposed to that of the duplex model. Given that changing-state sequences often lead to a more pronounced disruption of serial recall than deviation sequences, foreknowledge effects should be more pronounced in the changing-state conditions than in the deviation condition. Performance in the complex changing-state condition, in particular, should benefit from foreknowledge because complex changing-state sequences cause particularly large distraction effects (Bell et al., 2012; Röer et al., 2014a; Röer, Bell, & Buchner, 2015) that are more affected by foreknowledge (Röer, Bell, & Buchner, 2015) and habituation (Röer et al., 2014a) than other types of auditory distraction.

Pilot study

In a pilot study, we examined the effect of foreknowledge on four different distractor conditions in a repeated-measures design. The experiment was similar to Röer et al.'s (2015) Experiment 1, with the main difference that the experiment included the deviation condition and the simple changing-state condition in addition to the steady-state condition and the complex changing-state condition that were already included in Röer et al.'s Experiment 1.

Method

Participants

The data of two participants was not saved due to a power failure in the lab. The remaining sample consisted of 92 students at Heinrich Heine University Düsseldorf (66 of whom were female) with a mean age of 24 (*SD* = 5). All participants reported normal hearing and normal or corrected-to-normal vision.

Materials and procedure

Participants were seated in individual cubicles. Throughout the experiment, participants wore headphones with high-insulation hearing protection covers that were plugged directly into the Apple iMac computer, which controlled the experiment. Standard written instructions were presented on the computer screen. The participants were instructed to fully concentrate on the digit lists, and were informed that any words or sentences presented over the headphones were completely irrelevant for the task and should be ignored. They were told that they would not be tested on the distractors' content at any point in the experiment. They were not allowed to read the to-be-remembered digits aloud.

In the foreknowledge condition, a transcript of the to-be-ignored sequence was visually presented in 32 pt Monaco font for 16 sec before each trial. In addition to that, the sequence was presented auditorily during the first 8 sec of that interval. This type of warning was chosen because it was the most potent in reducing distraction in the study of Röer et al. (2015). In the without-foreknowledge block, the words "no information" were displayed in 32 pt Monaco font during the 16 sec interval, and no sound was played. After the 16 sec interval, a blank screen was shown for 1 sec, after which eight to-be-remembered digits were presented consecutively with a rate of 1 item per 1 sec in black 100 pt equidistant Monaco font on a white background. In each trial, the to-be-remembered numbers were randomly sampled without replacement from the set {1, 2, …, 9}. Immediately after the presentation of the last digit, eight question marks (one for each serial position) appeared on screen. This was the signal for the participants to start recalling the digits in the order of their presentation. Participants used the keyboard's number pad to enter the digits in forward order. Each number replaced one question mark. Participants could omit a serial position by pressing a "don't know" button on the keyboard, in which case the question mark was replaced by a hyphen. It was not possible to correct the responses. When all question marks had been replaced, participants received a feedback about how many digits were correctly remembered, and could start the next trial by clicking a continue button.

There were four distractor conditions. In the steady-state condition, a randomly selected one-syllable word was repeated 8 times (e.g., "black, black, black, black, black, black, black, black"). The deviation condition was identical to the steady-state condition, but the sixth steady-state standard distractor was replaced by a deviant distractor (e.g., "full, full, full, full, full, dog, full, full"). In the simple changing-state condition, 8 different distractor words were presented in random order (e.g., "moon, close, air, hot, tooth, real, sense, young"). In the complex changing-state condition, coherent sentences were presented (e.g., "Peel and quarter the onions and slice them into thin pieces, then add the tomatoes, then simmer it at medium heat"). The stimulus material was identical to that used in the study of Röer et al. (2015). In each block, the one-syllable words were sampled randomly from a pool of 128 of the most common monosyllabic words in the German language (e.g., "field, proud, young, near, now, left, friend, half"). All distractor sequences were spoken in the same male voice. The auditory distractor sequences lasted 8 sec each. All sounds were presented binaurally at approximately 65 dB(A).

As in previous studies (Hughes et al., 2013; Röer, Bell, & Buchner, 2015), there were two blocks of trials. In one block, participants were informed which auditory distractor sequence would be played during the presentation of the item list (with foreknowledge). In the other block, no information was given about the nature of the imminent distractor sequence (without foreknowledge). The order of the blocks was counterbalanced across participants. Each block consisted of 8 trials of each distractor condition. The trials within each block were presented in a random order.

Design

A 2 × 4 repeated-measures design was used with foreknowledge (with, without) and distractor type (steady state, deviation, simple changing state, complex changing state) as the independent variables and serial recall performance as the dependent variable. Performance was scored according to a strict serial-recall criterion (only digits recalled in the correct serial position were scored as correct). A multivariate approach was used for all within-subject comparisons. In our application, all multivariate test criteria correspond to the same (exact) F statistic, which is reported. The level of α was set to .05.

Results

A 2 × 4 MANOVA revealed a main effect of distractor type, $F(3, 89) = 31.99$, $p < .01$, $\eta_p^2 = .52$. As expected, the distractor sequences with auditory changes disrupted performance relative to the steady-state control condition, $F(1, 91) = 88.32$, $p < .01$, $\eta_p^2 = .49$. The main effect of foreknowledge did not reach the conventional level of statistical significance, $F(1, 91) = 2.87$, $p = .09$, $\eta_p^2 = .03$. However, the interaction between foreknowledge and distractor type was significant, $F(3, 89) = 3.37$, $p = .02$, $\eta_p^2 = .10$. Foreknowledge significantly reduced the distraction by complex changing-state sequences, $t(91) = 3.15$, $p < .01$, $d_z = 0.33$, but had no statistically significant effect on the distraction by steady-state sequences, $t(91) = 1.03$, $p = .31$, $d_z = 0.11$, the distraction by deviation sequences, $t(91) = 0.15$, $p = .88$, $d_z = 0.02$, or the distraction by simple changing-state sequences, $t(91) = -0.11$, $p = .91$, $d_z = -0.01$ (see Figure 1).

Discussion

In the pilot study, serial recall was significantly disrupted by task-irrelevant changes in the auditory channel. The disruption by changing-state sequences was more pronounced than the disruption by deviation sequences, which is a typical finding. Complex changing-state sequences (spoken sentences) produced the largest distraction effect. As expected, foreknowledge had no effect in the steady-state control condition, but it was effective in reducing disruption by complex changing-state sequences (coherent sentences), as in Röer et al.'s (2015) study. However, foreknowledge had no effect on either the deviation condition or the simple changing-state condition.

As a follow-up study, we performed a direct preregistered replication of the pilot study. Given that the pilot study already demonstrated that the effects of foreknowledge on auditory distraction are confined to complex changing-state material, one may question why a direct replication is necessary. However, we think there are good reasons for conducting a preregistered replication. (1) It is problematic to take the findings of a single experiment as definitive evidence because many findings in Psychology fail to replicate in direct preregistered replications (Open Science Collaboration, 2015). (2) The finding of Röer et al.

(2015) that specific foreknowledge reduced distraction by complex changing-state speech was interpreted as being fully consistent with the original finding of Hughes et al. (2013) that foreknowledge reduced attentional capture by auditory deviations. It seems surprising that foreknowledge improved performance in the complex changing-state condition, but had no effect on the deviation condition in the pilot study. Given the unexpected nature of this result, it seems preferable to perform a direct preregistered replication before drawing conclusions about this issue.

A second, related, concern might be why we performed a large pilot study before conducting the preregistered study. We think that this approach has several advantages. (1) A common concern against results-blind reviews and editorial decisions is that they may result in null findings that could be considered dull or uninteresting (Greve, Bröder, & Erdfelder, 2013) due to problems when executing an experiment that are not obvious at the stage of planning but become apparent when it is actually conducted. In the present case, it is important to show that we are able to find distraction by deviation, simple changing-state, and complex changing-state distractors (in comparison to the steady-state control condition), which is a necessary precondition for testing the effects of foreknowledge on the different types of distraction. We think that the pilot study yielded interesting findings, the replicability of which is to be rigorously tested in the preregistered follow-up study. (2) Obviously, the pilot study provides additional, valuable evidence for evaluating the effects of verbal warnings on auditory distraction. It seems reasonable to have more confidence in conclusions that are based on two different experiments than in conclusions that are only based on a single experiment. (3) The pilot study provides a good basis for an a priori power analysis. Given that the replication is a direct replication, it is easier than in many other situations to determine a priori the number of participants that are necessary to obtain the interaction between foreknowledge and distractor condition because there is a good basis for estimating the possible effect size.

Preregistered Study

The preregistered study is a direct replication of the pilot study.

Method

Materials and procedure

Materials and procedure are identical to those used in the pilot study.

Power analysis

The pilot study was used as the starting point for an a-priori power analysis. Based on the Pillai *V* as the multivariate test criterion for the critical foreknowledge by distractor type interaction and rounding down to the second decimal digit, we arrived at $V = .10$ and, hence, $f(V) = .33$ as a reasonable estimate of the population effect size of that interaction. Using this value as the population effect size and given desired levels of $\alpha = \beta = .05$, it is necessary to collect data of at least $N = 162$ participants in order to replicate the interaction between foreknowledge and distractor type (Faul, Erdfelder, Lang, & Buchner, 2007).

Analysis plan

The exact same analyses will be performed on the data as in the pilot study.

Replication in Germany (preapproved by Experimental Psychology)

The German replication study was approved in advance by Experimental Psychology, and conforms to the power calculations reported above. A preregistration protocol was published prior to the start of data collection at https://osf.io/h6ext/[1].

Differences from pre-data collection plan

We tested 163 participants, but one participant decided not to complete the experiment. The remaining sample consisted of 162 students (127 of whom were female) with a mean age of 23 ($SD = 5$).

Results

The main effect of distractor type was significant, $F(3, 159) = 37.76$, $p < .01$, $\eta_p^2 = .42$. The main effect of foreknowledge was not significant, $F(1, 161) = 2.64$, $p = .11$, $\eta_p^2 = .02$. The critical interaction between foreknowledge and distractor type was not significant, $F(3, 159) = 1.28$, $p = .28$, $\eta_p^2 = .02$. Foreknowledge reduced the distraction by complex changing-state sequences, $t(161) = 2.18$, $p = .03$, $d_z = 0.17$, but had no effect on the distraction by steady-state sequences, $t(161) = 1.00$, $p = .32$, $d_z = 0.08$, deviation sequences, $t(161) = 1.08$, $p = .28$, $d_z = 0.08$, and simple changing-state sequences, $t(161) = -0.45$, $p = .66$, $d_z = -0.04$.

Replication in Sweden

Immediately after the editorial approval of the replication in Germany by Experimental Psychology, but prior to the start of data collection, the opportunity arose to perform an additional replication in Sweden to see whether the same results could be obtained in a different lab with material in a different language (Swedish). This seemed to be a useful

[1] The detailed replication plan can be accessed directly at https://osf.io/h6ext/register/565fb3678c5e4a66b5582f67

addition to the preapproved data collection plan because reproducibility across labs is often considered the best way to test the reliability of an effect (Simons, 2014). Importantly, the data collection in Sweden was specified and preregistered prior to the start of the German data collection in the same preregistration protocol (https://osf.io/h6ext/; for details, find "Registration Form", then click on "Prereg Challenge"). As specified a priori in the preregistration protocol, the data were analyzed in two exploratory analyses (alone and combined with the German data). It was clear from the outset that, due to limited resources, the Swedish sample would have to be smaller than what was specified in the power analysis for the German sample. Despite this fact, we decided to jump at the opportunity and aimed at recruiting at least 80 participants. We continued collecting data until the end of the ongoing week, so that the final sample consisted of 88 participants (41 of whom were female) with a mean age of 27 (SD = 8).

In the Swedish sample, the main effect of distractor type was significant, $F(3, 85) = 23.44$, $p < .01$, $\eta_p^2 = .45$. The main effect of foreknowledge was not significant, $F(1, 87) = 1.70$, $p = .20$, $\eta_p^2 = .02$, and the critical interaction between foreknowledge and distractor type was not significant either, $F(3, 85) = 2.18$, $p = .10$, $\eta_p^2 = .07$. Foreknowledge reduced the distraction by complex changing-state sequences, $t(87) = 2.25$, $p = .03$, $d_z = 0.24$, but had no effect on distraction by steady-state sequences, $t(87) = 1.23$, $p = .22$, $d_z = 0.13$, deviation sequences, $t(87) = 0.84$, $p = .40$, $d_z = 0.09$, and simple changing-state sequences, $t(87) = -0.41$, $p = .68$, $d_z = -0.04$.

Combined Analysis

As specified a priori at https://osf.io/h6ext/, the Swedish data was also analyzed in a combined analysis together with the German sample to determine whether or not there are differences between the two data sets. The analysis is identical to those reported above with the only exception that lab (Germany, Sweden) was added as a between-subjects variable.

In the combined analysis, the main effect of distractor type was significant, $F(3, 246) = 49.00$, $p < .01$, $\eta_p^2 = .37$. The main effect of foreknowledge was significant as well, $F(1, 248) = 4.51$, $p = .03$, $\eta_p^2 = .02$, as was the critical interaction between foreknowledge and distractor type, $F(3, 246) = 3.33$, $p = .02$, $\eta_p^2 = .04$. Foreknowledge reduced the distraction by complex changing-state sequences, $t(249) = 3.13$, $p < .01$, $d_z = 0.20$, but had no effect on distraction by steady-state sequences, $t(249) = 1.58$, $p = .12$, $d_z = 0.10$, deviation sequences, $t(249) = 1.36$, $p = .18$, $d_z = 0.09$, and simple changing-state sequences, $t(249) = -0.61$, $p = .54$, $d_z = -0.04$. There was no difference in mean serial recall performance between German and Swedish participants, $F(1, 248) = 0.28$, $p = .60$, $\eta_p^2 < .01$. However, there was an interaction between lab and auditory distraction, $F(3, 246) = 3.08$, $p = .03$, $\eta_p^2 = .04$. Performance was very similar between the labs in the changing-state conditions, but German participants were (nonsignificantly) better than the Swedish participants in the steady-state condition and in the deviation condition. Importantly, however, the foreknowledge effect did not differ between labs, $F(1, 248) = 0.34$, $p = .56$, $\eta_p^2 < .01$, and there was no three way interaction between lab, auditory distraction, and foreknowledge, $F(3, 246) = 0.21$, $p = .89$, $\eta_p^2 < .01$.

Discussion

Consistent with the pilot study, foreknowledge had neither an effect on the deviation condition nor on the simple changing-state condition. The effect of foreknowledge on the complex changing-state condition was significant in both replication studies, but the critical interaction between foreknowledge and distractor type attained statistical significance only when the data of both replication studies were combined, and effect sizes were smaller than in the pilot study.

General Discussion

Consistent with previous studies (Hughes et al., 2013; Röer, Bell, & Buchner, 2015), foreknowledge about a simple changing state sequence did not help to attenuate distraction. Unexpectedly, foreknowledge about an imminent auditory deviation did not benefit performance either. Foreknowledge about complex changing-state sequences, in contrast, improved performance. However, the critical interaction between foreknowledge and distractor type attained significance only in the pilot study and in the combined analysis of both replication studies. Taken together, the results suggest that the effects of foreknowledge on auditory distraction are more limited than previously thought.

The main prediction of the duplex model (Hughes et al., 2013) is that the effects of foreknowledge differ between the deviation condition and the changing-state conditions. This difference was not tested in previous studies. The present study provides a direct test of the predicted dissociation, and provides clear evidence against the hypothesis that foreknowledge selectively benefits performance in the deviation condition, but has no effect on the changing state conditions. If anything, performance in the complex changing-state condition was improved by foreknowledge, while performance in the deviation condition was not. This finding disconfirms the prediction of the duplex model that the deviation effect is more amenable to cognitive control than the changing state effect. Given that the duplex model is based on multiple dissociations (Hughes, 2014), evidence against a single one does not necessarily refute the theory. However, the evidence in support of the duplex model is largely based on indirect findings (comparisons between experiments), and the present findings suggest that more direct evidence is needed before the model should be accepted as the standard explanation of auditory distraction effects.

According to the embedded-processes model (Cowan, 1995), foreknowledge should have a larger effect on those types of auditory distraction that are more effective in disrupting performance, simply because there is more room for improvement. The present results point in this direction because foreknowledge was most effective in attenuating the effects of complex changing-state sequences, which also caused the largest distraction effects. However, there was no linear increase of the effects of foreknowledge with increasing distraction because foreknowledge had no effect on the simple changing-state condition at all, despite a relatively large distraction effect in this condition.

To explain why performance in the complex changing-state condition was selectively improved by foreknowledge, one may be tempted to postulate that coherent sentences are "special" in the sense that they cause "semantic disruption" on top of the disruption caused by changing-state distractors and that only the semantic type of disruption can be diminished by cognitive control while distraction by perceptual changes cannot. This could be taken as suggesting that semantic distraction represents a distinct form of auditory distraction that should be distinguished from both order interference and attentional capture. However, such an interpretation would be problematic because it is contradicted by findings showing that the disruption of serial recall by sentential speech is independent of whether the speech is played in forward or backward direction (Jones, Miles, & Page, 1990; Röer, Körner, Buchner, & Bell, in press), which is inconsistent with a special role for semantic content as a cause of the disruption of serial recall, which does not rely on semantic processing (Marsh & Jones, 2010). An alternative view is that the diagnostic value of dissociations for identifying functionally different forms of auditory distraction is limited. Dissociations can often be found among tasks that tap the same cognitive construct (Kolers & Roediger, 1984) because each task does not represent a process-pure measure of the construct, but instead requires multiple cognitive operations. This complicates the interpretation of empirical dissociations because each component process may be responsible for the dissociation (Nairne, 2007). In the present case, it seems possible to argue that participants are particularly successful in converting meaningful, syntactically coherent speech into a verbal code that supports a stable representation of the upcoming distractor sequence when attending to a warning in the complex changing-state condition. This may help to build up a predictive model of the imminent distractor sequence, which would, in turn, reduce the disruptive effect of that distractor sequence. The same processes may be involved in the other conditions in principle. However, steady-state sequences are highly predictable and cause little distraction from the outset so that foreknowledge is hardly effective in further increasing predictability. The deviation sequences are slightly more effective in disrupting serial recall, but it may be difficult to build up a useful representation of the exact position of the deviant in the sequence. It may be equally difficult to convert a randomly assembled list of words into a stable representation of the upcoming distractor sequence, which may explain why there was no benefit of foreknowledge in the simple changing-state condition in all experiments (the same should be true for sequences of backward speech or foreign speech, but this remains to be tested in future experiments). In essence, then, performance in the complex changing-state condition may benefit from foreknowledge (a) because a complex changing-state sequence causes a particularly large disruption of serial recall, which provides the greatest potential for improvement, and (b) because meaningful, syntactically coherent speech can be easily processed when being attended before the trial, and can, therefore, be effectively converted into a predictive representation of the upcoming distractor sequence (cf. Röer, Bell, & Buchner, 2015). If this interpretation is correct, then it is not necessary to postulate distinct forms of distraction to explain the dissociation between conditions.

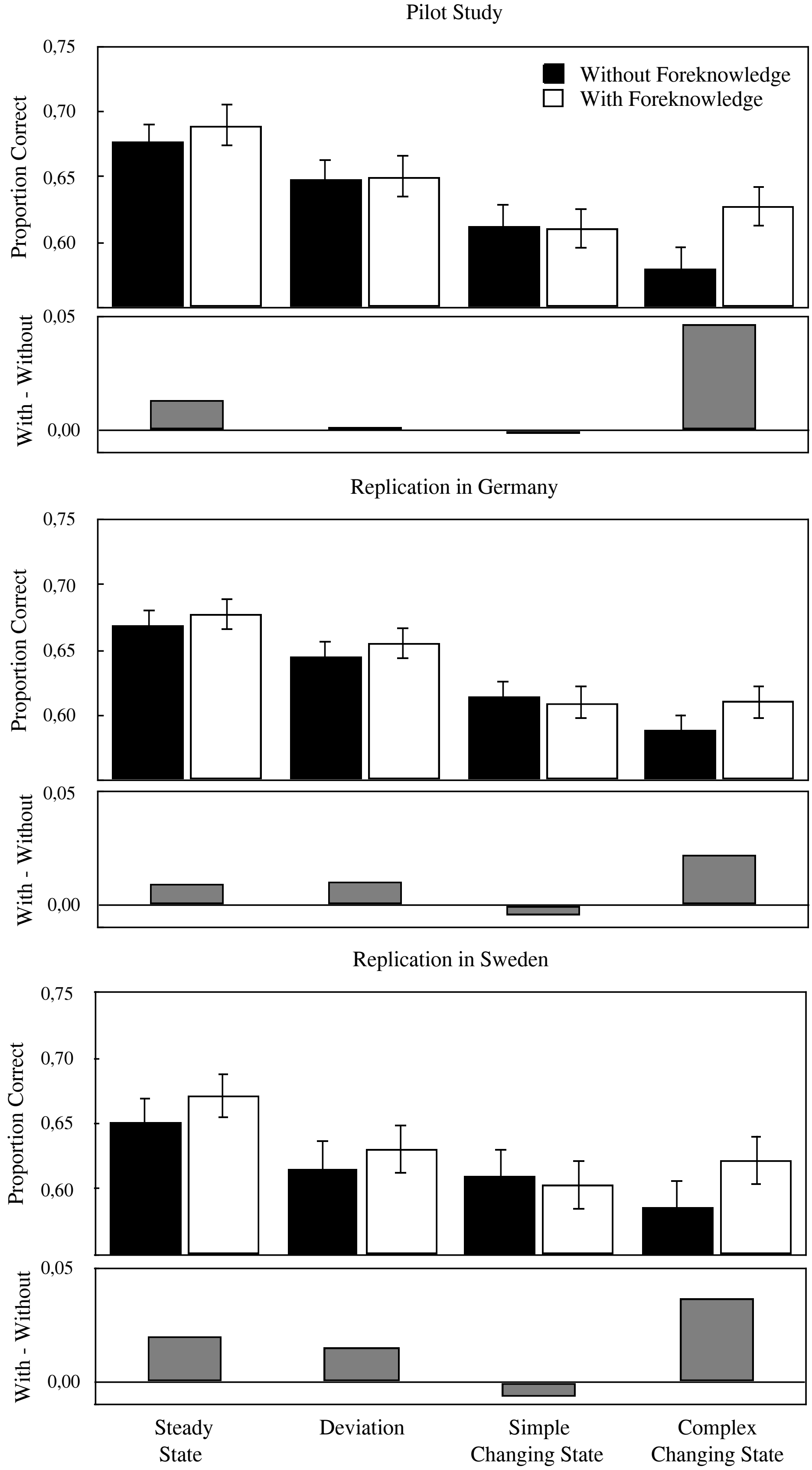

Figure 1: Proportion of correct responses as a function of foreknowledge and distractor type in the the pilot study and the replication studies in Germany and Sweden. The error bars represent the standard errors of the means. The gray bars show the foreknowledge effect (i.e., the difference between the with-foreknowledge condition and the without-foreknowledge condition).

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