Specific foreknowledge reduces auditory distraction by irrelevant speech

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Abstract

In a series of experiments it was tested whether distraction by changing state irrelevant speech is inevitable or can be modulated by foreknowledge of an imminent to-be-ignored distractor sequence. Participants were required to remember visually presented digits while ignoring background speech. In the foreknowledge condition of Experiment 1, the upcoming to-be-ignored sentence was presented auditorily and visually before each trial. With specific foreknowledge, the changing state irrelevant sound effect (here, increased disruption by sentences compared to repeated words) was significantly attenuated relative to a condition without foreknowledge. This finding was replicated in Experiment 2 in which the information about the upcoming auditory distractor speech was presented only in the visual modality. Experiment 3 showed that only specific foreknowledge of the auditory distractor material has beneficial effects on the ability to ignore distraction. The mere notification that an unspecified distractor sentence would be presented next had no effect on distraction. In Experiment 4, there was only a small and not statistically significant reduction of the irrelevant speech effect when lists of randomly selected words were used as distractor material, suggesting that foreknowledge effects are more pronounced for highly variable, meaningful distractor material. We conclude that the disruption of short-term memory by irrelevant speech is not purely a stimulus-driven process that is immune to top-down control. A significant proportion of the effect can be modulated by specific knowledge about an imminent distractor sequence.

Keywords: irrelevant sound effect, auditory distraction, short-term memory, attentional orienting, expectancy violation, attentional capture

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The attentional system has to keep a balance between two conflicting aims. In order to sample relevant environmental information for the purpose of goal-directed behavior, irrelevant information has to be deselected. Obviously, however, the processing of irrelevant information should not be suppressed completely because the relevance of information from an unattended channel might change. However, this openness of the cognitive system to unattended information comes at a cost. The fact that even working memory cannot be protected completely against unwanted input is illustrated by phenomena such as the irrelevant sound effect: the immediate recall of serial information is impaired when task-irrelevant information must be ignored (Beaman, Hanczakowski, Hodgetts, Marsh & Jones, 2013; Bell, Röer & Buchner, 2013; Elliott & Briganti, 2012; Klatte, Lachmann, Schlittmeier & Hellbrück, 2010; Sörqvist, Nöstl & Halin, 2012).

How does the cognitive system balance the conflicting goals of suppressing irrelevant distractors and remaining open for potentially relevant information? Working memory models such as the embedded-processes model (Cowan, 1995, 1999) that are based on research on the orienting reaction (Sokolov, 1963) give a simple answer that can be applied to explain many phenomena in selective attention research. Novel or unexpected stimuli that cannot be predicted based on previous experience elicit an orienting reaction, which causes the processing of this information to some extent in order to determine its relevance. As a consequence, ongoing task activity that requires attentional resources may suffer. To the extent that the distractor becomes predictable based on previous information, the orienting reaction attenuates, and primary task performance recovers. However, if changes from the predicted pattern occur, the orienting reaction is elicited again and attention is drawn to the deviant event. Two kinds of changes can be differentiated that are of importance: changes that occur globally and changes that occur locally.

Global changes: The auditory deviant effect

Attention capture by a sudden unpredictable change from the previous stimulus pattern has been extensively documented. Auditory stimuli that deviate from a regular stimulus sequence elicit a so-called mismatch negativity (Schröger & Wolff, 1998) that may—when it exceeds a certain threshold—be associated with a full attention switch to the auditory modality even if attention is focused on the visual modality (Berti & Schröger, 2003; Näätänen, 1990; Näätänen & Winkler, 1999). Recently it has been shown that these deviants also cause a pronounced decrement in the serial recall of visually presented item lists. A deviant could be, for instance, a distractor spoken by a different voice (Sörqvist, 2010) or a distractor that is out of sync relative to other, regularly presented distractors (Hughes, Vachon & Jones, 2005). Serial recall in trials with such unexpected auditory deviants is typically worse than in trials without deviants (see also, Hughes, Vachon & Jones, 2007; Lange, 2005; Marsh, Röer, Bell & Buchner, 2014; Röer, Bell & Buchner, 2014c). The expectancy violation, however, must not necessarily occur within a trial. Unexpected changes across trials produce a similar effect. When, after many trials of ignoring the same distractor word pair, a new distractor word pair is presented, serial recall performance drops markedly (Röer, Bell, Dentale & Buchner, 2011; see also Vachon, Hughes, & Jones, 2012). In general, the amount of attentional capture seems to be best predicted by the degree to which the deviant violates an expectation based on previous auditory stimulation (Nöstl, Marsh & Sörqvist, 2012; Parmentier, Elsley, Andres & Barcelo, 2011; Röer et al., 2014c; Vachon et al., 2012).

Recently, Hughes, Hurlstone, Marsh, Vachon, and Jones (2013) examined the effect of foreknowledge on the disruption caused by auditory deviants. Shortly before each trial they displayed a visual notice informing the participants whether or not a voice change would occur in the next trial. They found that foreknowledge eliminated the auditory deviant effect. This result can be interpreted as further evidence that auditory distraction is negatively related to the distractor's predictability. Foreknowledge makes the deviant stimulus more predictable, and with that reduces its disruptive effect. A similar pattern can be found when looking at the across trial performance in experiments with unexpected auditory deviants. Typically the disruption of serial recall is most pronounced when the deviant stimulus is encountered the first time and gradually recovers with repeated presentation when it becomes more predictable (Marsh et al., 2014; Röer et al., 2014c; Vachon et al., 2012).

Local changes: The changing state effect

Another important determinant of the disruptive effect of auditory distractors on serial recall is the amount of local change within the to-be-ignored sequence (i.e., changes between two adjacent distractors). The changing state effect refers to the phenomenon that the disruptive effect of auditory distractors varies as a function of the amount of abrupt changes in the amplitude or frequency spectrum (e.g., Schlittmeier, Weißgerber, Kerber, Fastl & Hellbrück, 2012). For instance, changing state sequences—such as melodies, speech or generally speaking a sequence composed of different distractor items—have a large disruptive effect on serial recall, whereas steady state sequences in which a single distractor item is constantly repeated produce little or no interference compared to a quiet control condition (Bell, Dentale, Buchner & Mayr, 2010; Jones, Madden & Miles, 1992). Accordingly, sequences without any local changes such as a continuously presented vocal (LeCompte, 1995) or pink noise (Schlittmeier, Hellbrück & Klatte, 2008) interfere only marginally with serial recall, if at all. It has been shown frequently that two alternating distractor items suffice to produce a changing state state effect (e.g., Jones et al., 1992), and that sequences containing a high amount of abrupt, unpredictable changes (e.g., natural speech) typically have a very large disruptive effect on serial recall (Röer, Bell & Buchner, 2014a; Schlittmeier et al., 2012).

According to attention-based accounts such as the embedded-processes model (Cowan, 1995, 1999), the changing state effect is just another example of the general principle that distraction increases with the unpredictability of the distractor material. The greater disruptive potential of acoustically variable compared to repetitive distractor sequences is explained by an orienting reaction that is elicited by changes in the auditory modality. Steady state sequences consisting of sound repetitions with a constant presentation rate are the most predictable distractor sequences conceivable. Accordingly, these distractor sequences often fail to produce a measurable disruptive effect.

There are, however, theoretical accounts that attribute the changing state effect to a completely different kind of interference. According to the duplex-mechanism account of auditory distraction (Hughes et al., 2005, 2007), the changing state effect is the consequence of a conflict between relevant and irrelevant order information (cf. Jones, Beaman & Macken, 1996). Here, the assumption is that certain features of the acoustic environment are obligatorily processed. Specifically, whenever abrupt changes in physical stimulus characteristics occur, the to-be-ignored auditory information is preattentively segmented into auditory objects, the order of which is automatically registered by an obligatory seriation process. Disruption of serial recall occurs because this seriation of the irrelevant sound interferes with the intentional maintenance of the order of the to-be-remembered items. Steady state distractor sequences are assumed not to interfere with the maintenance of the to-be-remembered order information at all. This is so because sequences consisting of one repeated auditory distractor do not contain any (task-irrelevant) order information, and representing them does not require seriation. According to the duplex-mechanism account the changing state effect is solely attributed to interference caused by the preattentional seriation of the to-be ignored stream. Attentional processes are not involved (Hughes et al., 2007; Vachon et al., 2012). A direct implication of this model is that the processing of the irrelevant material is not under cognitive control, and the predictability of the to-be-ignored material must not affect interference (cf. Tremblay & Jones, 1998). Attention only plays a role when the sound is of personal relevance (e.g. when a mother is hearing her own baby's cries) or when it grossly violates the expected continuation of a recently presented auditory context (e.g., when a voice change occurs), which has detrimental effects on the encoding of the to-be-remembered items (Hughes et al., 2005). Within the duplex-mechanism account, the expectancy-based auditory deviant effect and the seriation-based changing state effect are attributed to different mechanisms. While the auditory deviant effect may be affected by the auditory material's predictability, the changing state effect must not (Hughes et al., 2013).

Is the changing state effect affected by foreknowledge?

The embedded-processes model (Cowan, 1995, 1999) and the duplex-mechanism account (Hughes et al., 2005, 2007) agree in their explanation of the auditory deviant effect inasmuch as it is not entirely stimulus-driven, but to some extent under cognitive control. Both theories disagree, however, in their explanation of the changing state effect. According to the embedded-processes model disruption by changing state sounds, too, should be a function of the distractor's predictability. According to the duplex-mechanism account, different types of processes form the basis of these effects. Disruption by changing state sounds is attributed to a preattentional conflict, which results from the automatic processing of the distractor's acoustic properties. Therefore it must be unaffected by the predictability of the to-be-ignored material. Empirical evidence in favor of this assumption comes from Hughes et al. (2013), who examined the effect of foreknowledge on the interference caused by changing state irrelevant sounds. Before each trial a visual notice informed participants whether the next trial would be a changing state trial or a steady state trial. This unspecific warning had no effect on serial recall performance. A similar warning in another experiment had eliminated the auditory deviant effect, which led Hughes et al. (2013) to conclude that there are two distinct forms of auditory distraction. While the expectancy-based auditory deviant effect is open to cognitive control, the changing state irrelevant sound effect is immune to top-down influences: "Attentional capture by a deviant can be resisted, disruption by continuously changing sounds is indomitable." (p. 11). On the basis of this experiment alone, however, it is difficult to decide, whether there is a general indomitability of changing state disruption. Possible limitations include (1) the specificity of the foreknowledge and (2) the distractor material's complexity.

Hughes et al. (2013) have used an unspecific warning that only informed participants whether the upcoming distractor sequence was "steady state" or "changing state". Such an unspecific warning may be insufficient to reduce the unpredictability of the upcoming distraction. What is more, it remains unclear whether this warning provided any foreknowledge at all relative to the no-warning control condition. In that condition participants also knew after the onset of the second distractor item—that is, after 0.5 seconds, and thus still during the presentation of the first item—that the distractor sequence was "steady state" (when the second distractor item was the same as the first one) or "changing state" (when the second distractor item was different from the first one). This stands in contrast to the experiment with auditory deviants, in which participants in the no-warning condition knew only after half of the to-be-remembered items were presented whether the distractor sequence contained an auditory deviant, or not. Thus, while an unspecific warning made an upcoming changing state sequence only slightly more predictable, it helped considerably to reduce the unpredictability of the upcoming distraction by an auditory deviant. Moreover, results from Bell et al. (2012) indicate that specific foreknowledge may indeed be necessary to generate a useful expectation about the upcoming distractor sequence. They found that pre-presenting the later to-be-ignored sequence before the trial reduced the disruptive potential of that sequence drastically. When the participants were given the opportunity to familiarize themselves with a similar, but different sequence, no such reduction was observed. Further evidence that specific foreknowledge is needed comes from studies in which a violation of a previously formed stimulus-specific expectation caused a drop in recall performance (Röer et al., 2014c; Röer et al., 2011; Vachon et al., 2012), for instance when after many trials of ignoring the same distractor sequence, a new sequence was played (Röer et al., 2011).

The second possible limitation concerns the type of the distractor material. Hughes et al. (2013) used the same distractor items (spoken letters) in a different order for each trial. These letters were as similar as possible with respect to length, intonation, and timing. So even in the no-warning condition, participants actually knew a great deal about the upcoming distraction. For instance, they knew that the distractors would all be equally loud (65 dB[A]) and long (250 ms), and that the inter-stimulus intervals would also be of the same length (350 ms). Thus, there was a very simple rhythmicity in the entire distractor sequence which was equally predictable in the changing state and the steady state condition. Therefore, simple and acoustically predictable sequences are probably not ideal for investigating possible foreknowledge effects on changing state distraction because foreknowledge can add very little to what is already known. Complex sequences such as natural speech contain more changes in amplitude and frequency and, more importantly, these changes do not occur in a simple, highly regular rhythmicity. This might provide a greater potential for a reduction of the distractor's unpredictability through specific foreknowledge. Evidence for this assumption comes from a recent study in which we found that the disruptive effects of speech and melodies relative to a quiet control condition were markedly reduced after eight repetitions of the same distractor sequence (Röer et al., 2014a). This finding stands in contrast to the absence of habituation effects when simple lists of changing words are used as distractor material (Beaman & Röer, 2009; Jones, Macken & Mosdell, 1997; Röer et al., 2011; Tremblay & Jones, 1998). Similarly, it seems possible that the top-down control of distraction by foreknowledge may depend on the type of distractor material used. Therefore, we varied the type of the to-be ignored auditory material across experiments (complex sentences in Experiments 1-3, and lists of one-syllable words in Experiment 4).

In sum, an unspecific warning and simple distractor material may not be the most promising approach to reduce the unpredictability of an imminent to-be-ignored distractor sequence. Therefore, in the present series of experiments, our aim was to take a closer look at how general the immunity of the changing state effect to foreknowledge manipulations really is. In Experiment 1, we therefore tried to maximize the chances to find significant foreknowledge effects. The following changes were made in comparison to the procedure of Hughes et al. (2013). First, participants received specific foreknowledge of the distractor material. Hughes et al. (2013) only informed their participants about whether a steady state or a changing state trial was about to follow. This unspecific foreknowledge did not suffice to reduce the distractor's disruptive effects. However, specific foreknowledge may be necessary to build up a mental representation of an upcoming changing state distractor, and only in this case can we expect to observe an effect of foreknowledge on serial recall performance. Second, the upcoming distractor sequence was presented both visually and auditorily to provide participants with foreknowledge about the distractor material's acoustic properties that are known to be mainly responsible for its disruptive potential. Third, we used complex sentences instead of regular lists of one-syllable words to elicit a sufficiently large changing state effect, which should increase the probability of finding a modulation thereof. Across Experiments 2-4, we systematically reduced the differences to Hughes et al. (2013) to identify the boundary conditions for observing foreknowledge effects with changing state auditory distractor material.

Experiment 1

Method

Participants

A total of 44 students (32 women) at Heinrich-Heine-Universität Düsseldorf were paid or received course credit for participating. Their ages ranged from 19 to 40 years (M = 25). All participants reported normal hearing and normal or corrected to normal vision.

Materials

For each trial eight to-be-remembered numbers were sampled randomly without replacement from the set {1, 2, ... 9}. They were presented consecutively at a rate of 1 per second (800 ms on, 200 ms off) in 72 point equidistant Monaco font on a white background in the center of the 19″ computer screen. From a viewing distance of 45 cm each number subtended a vertical visual angle of 1.49° and a horizontal angle of 0.92°.

Auditory distractor sequences were 16 steady state and 16 changing state sequences. For the changing sequences we used German spoken texts that had already produced a reliable changing state effect before (Bell et al., 2012). The texts' contents represented eight different categories (weather forecast, prose text, cooking recipe, scientific textbook, poem, operating manual, road message, aphorism) and were spoken by the same male voice (e.g., "Pour water, lemon juice, and sugar in a cooking pot. Then stir gently until it boils and gradually fold in beaten egg white."). For the steady state sequences a randomly selected monosyllabic word from these sentences was repeated 18 times. This corresponded to the mean number of words in the changing state sequences. The auditory distractor sequences lasted 8 s each. All sounds were presented binaurally at about 63 dB(A).

Procedure

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 on the computer screen informed participants that any sound was task-irrelevant and that the to-be-remembered items must not be pronounced.

Participants familiarized themselves with the serial recall task in 8 training trials during which no distractors were played. Then participants completed two blocks of 16 experimental 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 beforehand (without foreknowledge). The order of the blocks was counterbalanced between participants. The distractors were randomly selected without replacement.

In the "with foreknowledge" block, a visual transcript of the to-be-ignored sequence was presented for 16 seconds, and the sequence was presented auditorily during the first 8 seconds of that interval. In the "without foreknowledge" block the notice "no information" was displayed for 16 seconds, and no sound was played. After that (and independent of the auditory distractor condition) a red traffic light was shown at the center on the screen, which first turned yellow and then green to signal the onset of the to-be-remembered numbers. Immediately after each trial, participants recalled the numbers in the order in which they had been presented. A series of eight question marks (one for each of the serial positions) prompted the forward serial recall. Participants used the keyboard's number pad to enter the items in the order in which they had been presented. Each number replaced one question mark. Participants could omit a serial position by pressing a "don't know" button on the keyboard. In this case a hyphen replaced the corresponding question mark. It was not possible to correct a response. Provided the last question mark had been replaced, recall could be terminated by pressing the space bar. Performance feedback was given after each trial.

The experiment took approximately 25 min to complete, after which participants were offered an explanation as to the purpose of the experiment.

Design

A 2 × 2 repeated measures design was used with auditory distractor condition (changing state, steady state) and foreknowledge (with foreknowledge, without foreknowledge) as the independent variables and serial recall performance as the dependent variable (numbers were only scored as correct when they were reproduced in the serial position in which they had been presented). Of primary interest was the interaction between the independent variables. Specifically, the difference in recall performance between the changing state and the steady state condition, that is, the changing state effect, should be smaller with foreknowledge than without if specific foreknowledge affects the changing state effect. Given a total sample size of $N = 44$, $\alpha = \beta = .05$, and the assumption that the average population correlation between the two levels of the difference variable is $\rho = .5$, an effect of size $f = .28$ could be detected (Faul, Erdfelder, Lang & Buchner, 2007).

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 for all analyses. Partial eta squared (η_p^2) is reported as a measure of the sample effect size.

Results

Figure 1 illustrates the serial recall performance as a function of auditory distractor and foreknowledge conditions. A 2×2 MANOVA yielded significant main effects of auditory distractor condition, $F(1,43) = 21.40$, $p < .001$, $\eta_p^2 = .33$, and foreknowledge, $F(1,43) = 8.82$, $p = .005$, $\eta_p^2 = .17$. Most importantly, the interaction between these variables was significant, $F(1,43) = 6.06$, $p = .018$, $\eta_p^2 = .12$, reflecting that the changing state effect was smaller with foreknowledge than without. The typical difference between changing state and steady state sequences (e.g., Bell et al., 2010) was significant both with and without foreknowledge, but the effect was smaller with foreknowledge, $t(43) = 2.60$, $p = .013$, $\eta_p^2 = .14$, than without foreknowledge, $t(43) = 5.04$, $p < .001$, $\eta_p^2 = .37$. Finally, performance in the steady state condition was independent of foreknowledge, $t(43) = 0.53$, $p = .598$, $\eta_p^2 = .01$, but in the changing state condition performance was better with foreknowledge than without, $t(43) = 3.44$, $p = .001$, $\eta_p^2 = .22$.

Discussion

In the foreknowledge condition, in which participants had the opportunity to read and listen to a subsequently played distractor sentence before each trial, the changing state effect was markedly reduced compared to a control condition in which no such information was given. While foreknowledge had no effect on serial recall when steady state sounds were played, it benefitted participants greatly in the changing state condition. These results are in line with those from our experiments on auditory preexposure (Bell et al., 2012), in which presenting the to-be-ignored distractor sequence three times in a passive listening phase before each trial considerably attenuated the auditory distraction effect compared to a control condition without preexposure. Experiment 1 extends these findings by showing that the disruption by changing state sounds can be reduced even after a single pre-presentation of the distractor sequence.

In the foreknowledge condition the distractor sequence was presented both auditorily and as a visual transcript on the screen. Thus, it is difficult to attribute the attenuation of the changing state effect to either one or the other. Against the backdrop of the null results reported by Hughes et al. (2013) it seems possible that the reduction in disruption in Experiment 1 may simply stem from the modality-specific preexposure to the acoustic characteristics of the stimulus as it was previously demonstrated in habituation studies (Banbury & Berry, 1997; Bell et al., 2012; Morris & Jones, 1990). Thus, it is necessary to investigate whether the foreknowledge benefit in the changing state condition is tied to the auditory presentation of the distractor sequence. In Experiment 2, we therefore omitted the auditory pre-presentation, and provided only visual information in the foreknowledge condition, so that the first and only time a distractor sequence was encountered auditorily was parallel to the presentation of the to-be-remembered items. If the foreknowledge benefit was only due to the modality-specific pre-presentation of the sequence, then the benefit should no longer be observed in Experiment 2.

Experiment 2

Method

Participants

A total of 46 students (23 women) at Heinrich-Heine-Universität Düsseldorf were paid or received course credit for participating. Their ages ranged from 19 to 39 years (M = 24). All participants reported normal hearing and normal or corrected to normal vision.

Materials, Procedure, and Design

Materials, Procedure, and Design were identical to those of Experiment 1 with the exception that the auditory presentation of the to-be-ignored sequence in the "with foreknowledge" block was omitted. Given a total sample size of N = 46 and statistical power considerations identical to those of Experiment 1 in all other respects, an effect of size f = .27 could be detected.

Results

Figure 2 illustrates the serial recall performance as a function of auditory distractor and foreknowledge conditions. There was a main effect of auditory distractor condition, $F(1,45) = 46.22$, $p < .001$, $\eta_p^2 = .51$, but no main effect of foreknowledge on serial recall performance, $F(1,45) = 1.55$, $p = .220$, $\eta_p^2 = .03$. Most importantly, and parallel to Experiment 1, there was an interaction between the auditory distractor and foreknowledge conditions, $F(1,45) = 8.96$, $p = .004$, $\eta_p^2 = .17$. Again, the changing state effect, that is, the difference between changing state and steady state sequences, was significant both with and without foreknowledge, but the effect was smaller with foreknowledge, $t(45) = 3.97$, $p < .001$, $\eta_p^2 = .26$, than without foreknowledge, $t(45) = 6.80$, $p < .001$, $\eta_p^2 = .51$. As in Experiment 1, performance in the steady state condition was independent of foreknowledge, $t(45) = 0.96$, $p = .342$, $\eta_p^2 = .02$, but in the changing state condition performance was better with foreknowledge than without, $t(45) = 3.24$, $p = .002$, $\eta_p^2 = .19$.

Discussion

The results of Experiment 2 conceptually replicate those of Experiment 1, in that participants benefited from foreknowledge of the to-be-ignored task-irrelevant sounds. The present results further validate the finding that informing about upcoming distractor sequences reduces the changing state effect. This is all the more interesting because the distractor sequence was not presented auditorily prior to each trial, but only as a visual transcript on the computer screen. To our knowledge, this is the first demonstration of a foreknowledge benefit without actually presenting the irrelevant speech. The auditory distractor sequence was first encountered during the presentation of the to-be-remembered item list. Thus, habituation could not have occurred to physical stimulus features such as voice, intonation, loudness, or timing. Instead, participants benefited solely from the fact that they knew which distractor text would be played in the next trial, that is, from a content-specific, but physically abstract expectation. Given that the disruptive potential of the distractors was reduced although the distractors were played during serial recall for the very first time, the finding indicates that expectancy-based processes may have a larger impact on the disruptive effects of a distractor sequence than the novelty of the stimulus per se. It fits well with the results obtained by others (Parmentier et al., 2011; Vachon et al., 2012; Nöstl et al., 2012) that expectancy violation rather than novelty determines a distractor's potential to disrupt serial recall. This may well represent two sides of the same coin: Whereas those studies focused on the *detrimental* effects of *violated* expectations on serial recall, the present results exemplify the *benefits* of *confirmed* expectations.

The present Experiments 1 and 2 show that foreknowledge about the upcoming distractor reduces the changing state effect, whereas Hughes et al. (2013) had found the changing state effect to be unaffected by foreknowledge. These two types of findings may be reconciled by taking a closer look at the kind of foreknowledge that was available to the participants. Hughes et al. (2013) informed their participants that the upcoming distractor sequence was "steady state" or "changing state", which may be considered a relatively unspecific warning signal. Despite this warning, more specific characteristics of the distractors are still largely unpredictable and no specific expectation can be formed. In the present Experiments 1 and 2, in contrast, the transcript of the distractor sequence allowed the participants to build up a specific expectation. It seems plausible from this perspective that the degree to which the changing state effect can be modulated depends on whether the foreknowledge provided is sufficient to build up a specific expectation about the upcoming distraction.

Experiment 3 was conducted to test this hypothesis empirically. Parallel to Hughes et al. (2013), we only used an unspecific warning signal, in that we informed participants in the foreknowledge condition only whether the upcoming distractor sequence would be a sentence (i.e., changing state) or a repeated word (i.e., steady state). If specific foreknowledge is necessary for generating a useful expectation about the upcoming distraction, then the changing state effect must not be reduced by this type of warning signal.

Experiment 3

Method

Participants

A total of 51 students (36 women) at Heinrich-Heine-Universität Düsseldorf were paid or received course credit for participating. Their ages ranged from 19 to 40 years (M = 24). All participants reported normal hearing and normal or corrected to normal vision.

Materials, Procedure, and Design

Materials, Procedure, and Design were identical to those of Experiments 1 and 2 with the exception that in the "with foreknowledge" block "sentence" or "word" appeared on screen for 16 seconds to inform participants that the upcoming distractor was a sentence or a repeated word, respectively. Given a total sample size of N = 51, and statistical power considerations identical to those of Experiments 1 an 2 in all other respects, an effect of size f = .26 could be detected.

Results

Figure 3 illustrates the serial recall performance as a function of auditory distractor and foreknowledge conditions. There was a main effect of auditory distractor condition, $F(1,50)$ = 68.54, p < .001, η_p^2 = .58, but no main effect of foreknowledge on serial recall performance, $F(1,50)$ = 0.31, p = .579, η_p^2 = .01. Importantly, there was no interaction between the auditory distractor and foreknowledge conditions, $F(1,50)$ = 0.01, p = .919, η_p^2 < .01. This perfectly replicates the findings of Hughes et al. (2013), who also found no influence of an unspecific warning signal on the changing state effect. The size of the changing state effect with foreknowledge, $t(50) = 5.67$, $p < .001$, $\eta_p^2 = .39$, was comparable to that without foreknowledge, $t(50) = 6.41$, $p < .001$, $\eta_p^2 = .45$. Serial recall performance did not differ as a function of foreknowledge in the changing state condition, $t(50) = 0.32$, $p = .749$, $\eta_p^2 < .01$, and in the steady state condition, $t(50) = 0.53$, $p = .596$, $\eta_p^2 = .01$.

Discussion

The beneficial effect of foreknowledge on serial recall disappears when only an unspecific warning is provided. This is fully in line with Hughes et al. (2013), who found the same pattern of results when task-irrelevant letters were used as to-be-ignored distractors and participants received the unspecific instruction to expect a changing state distractor (a random sequence of spoken letters) or a steady state distractor (a sequence consisting of one repeated letter). Such unspecific warning signals are insufficient for generating a specific and thus useful expectation about the upcoming distractor which remains highly unpredictable. This is in contrast to the present Experiments 1 and 2, in which specific information was given that rendered the upcoming distractor highly predictable and reduced the changing state effect. An interesting question is why in the experiments by Hughes et al. (2013) the instruction to expect a "changing state" or a "steady state" distractor sequence had no effect on serial recall (i.e., the instructions did not reduce the changing state effect), but the instruction to expect a distractor sequence containing a "deviant" or "no deviant" benefited serial recall performance (i.e., the instructions reduced the deviant effect). At the surface, both types of instructions seem to be similarly unspecific. However, this is not the case. Their "deviant" sequences were identical to their "no deviant" sequences except that the sixth letter was conveyed in the other voice (e.g., in a male voice when all other letters were conveyed in a female voice or vice versa). Thus, the instruction to expect a deviant distractor sequence was not at all unspecific, but instead was very specific. Participants knew with the onset of the first distractor letter (i.e. shortly before the presentation of the to-be-remembered list) that this letter will be played five times, and that the voice pronouncing the letter would change for the sixth item and then back again for the remaining letters. In other words, this "unspecific" warning provided just as much foreknowledge as a specific warning in form of a visual transcript of the distractor sequence on the computer screen would have provided. This instruction appeared to be sufficient for generating a useful expectation about the upcoming deviant and helped reducing its disruptive effect just like the specific instructions in the present Experiments 1 and 2 helped reducing the changing state effect. Hence, the present experiments and those of Hughes et al. (2013) are perfectly in line in showing that both the deviant effect and the changing state effect can be reduced by specific instructions whereas the latter cannot be reduced by unspecific instructions that are insufficient for generating a useful expectation about the upcoming distractor sequence. In other words, whether or not an instruction is specific in the context discussed here can only be judged relative to the degree to which it reduces the uncertainty about the upcoming distractor.

Naturally, the foreknowledge effect without auditory preexposure (Experiment 2) appears to be somewhat limited to a certain category of distractor sequences (i.e., sentences that can be converted into a visual transcript and are not too difficult to remember such that a stable internal representation can be established). Foreknowledge can reduce only little of the auditory distractor's unpredictability if the sequences are very predictable from the outset such as steady state sequences or changing state sequences that consist of only two alternating distractor items. It also seems rather difficult to reduce the disruptive effect of an upcoming sequence of abstract sounds that can barely be converted into a visual transcript (e.g., construction noise). The same might be true for material such as foreign speech or a list of randomly assembled words. In these cases, advance information about the distractor material may not result in a significant reduction of the distractor effect because, in the few seconds during which that information is available, participants cannot establish a stable internal representation of the distractor material that helps to reduce the material's unpredictability. In Experiment 4 we tested this hypothesis empirically. To this end we replaced the irrelevant speech with lists of randomly assembled words. Parallel to Experiment 2 a condition without foreknowledge was compared to a condition in which specific foreknowledge was given in terms of a visual transcript of the to-be-ignored sequences. If the foreknowledge effect depends on the use of coherent natural speech that facilitates the establishing of a stable internal representation, then we would expect the effect of foreknowledge to disappear in Experiment 4.

Experiment 4

Method

Participants

A total of 101 students (72 women) at Heinrich-Heine-Universität Düsseldorf were paid or received course credit for participating. Their ages ranged from 18 to 45 years (M = 24). All participants reported normal hearing and normal or corrected to normal vision.

Materials and Procedure

Materials and Procedure were identical to those of Experiment 2 except for the distractor material. For the auditory distractor sequences the 400 most common monosyllabic words in the CELEX German language corpus (Baayen, Piepenbrock & van Rijn, 1993) were selected. Numerals (e.g., eins [one], zwei [two]), names (e.g., Fritz, Hans), and geographical terms (e.g., Rhein [Rhine], Köln [Cologne]) were excluded. For the changing state sequences eight words were randomly drawn from this set of words (e.g., Feld [field], stolz [proud], jung [young], nah [near], nun [now], links [left], Freund [friend], halb [half]). For the steady state sequences a randomly selected word was repeated eight times. The distractor words were spoken by a male voice and were equivalent with respect to duration, intonation, and loudness. Sounds were presented binaurally at about 63 dB(A).

Design

As in Experiments 1, 2, and 3 the interaction between the auditory distractor condition (changing state, steady state) and foreknowledge (with foreknowledge, without foreknowledge) was of primary interest. Based on the assumption that the effect of foreknowledge on serial recall should be eliminated when simple, contextless sequences of words, and therefore hard-to-remember distractor material is used, it seemed important to increase the sensitivity of the study. The total sample size was thus increased substantially to $N = 101$, so that given $\alpha = \beta = .05$ and an average population correlation between the two levels of the difference variable of $\rho = .5$, an effect of size $f = .18$ could be detected.

Results

Figure 4 shows the serial recall performance as a function of auditory distractor and foreknowledge conditions. There was a main effect of auditory distractor condition, $F(1,89) = 55.20$, $p < .001$, $\eta_p^2 = .38$, but no main effect of foreknowledge on serial recall performance, $F(1,89) = 0.35$, $p = .852$, $\eta_p^2 < .01$. The interaction between the auditory distractor and foreknowledge conditions from Experiment 2 was no longer significant, $F(1,89) = 1.72$, $p = .192$, $\eta_p^2 = .02$. The size of the changing state effect was comparable with and without foreknowledge, $t(89) = 5.02$, $p < .001$, $\eta_p^2 = .22$, and, $t(89) = 6.24$, $p < .001$, $\eta_p^2 = .30$, respectively. Serial recall performance did not differ as a function of foreknowledge in the changing state condition, $t(89) = 0.60$, $p = .548$, $\eta_p^2 < .01$, and in the steady state condition, $t(89) = 1.33$, $p = .187$, $\eta_p^2 = .02$.

Discussion

When lists of randomly assembled words are used as distractor material, the reduction of disruption by foreknowledge was no longer statistically significant. This is entirely consistent with the absence of foreknowledge effects on the disruptive potential of lists of one-syllable words reported by Hughes et al. (2013). Note, however, that descriptively, the disruptive effect of auditory distractors was still somewhat smaller with foreknowledge ($\eta_p^2 = .22$) than without foreknowledge ($\eta_p^2 = .30$). This may indicate that some of the advance information was beneficial for reducing distraction, but this is purely speculative. Thus, there seem to be boundary conditions for the effect of foreknowledge on changing state speech. First, as Experiment 3 has shown, the warning has to be specific. Second, even if a specific forewarning is provided, only the disruption by coherent sentences is significantly reduced; when highly regular lists of one-syllable words are used as distractor material there is only a non-signifiant trend towards a reduction of interference. The theoretical implications of these findings are discussed below.

General Discussion

The present series of experiments provides clear evidence that foreknowledge can reduce the disruptive effect of irrelevant speech. Experiments 1 and 2 demonstrate that auditory distraction by changing state sounds is not immune to foreknowledge effects. Two experimental conditions were compared. In the foreknowledge condition, participants were given detailed information before each trial specifying the distractor sequence that was about be played. In the condition without foreknowledge, no such information was given. Compared to the latter condition the changing state irrelevant sound effect was markedly reduced when foreknowledge was provided. In Experiment 1, the upcoming distractor sequence was presented auditorily and as a visual transcript prior to each trial. When the auditory preexposure to the distractors was omitted in Experiment 2, the results of Experiment 1 were replicated. Importantly, this result excludes the possibility that the foreknowledge effect was only due to habituation, because in Experiment 2 the physical sequence was not presented before the trial began, and thus habituation cannot have occurred. Thus, disruption by changing-state irrelevant sound can be effectively reduced by foreknowledge, and is therefore susceptible to cognitive control. This finding seems most compatible with a prediction-based account of auditory distraction. According to the embedded-processes model (Cowan, 1995, 1999) novel and unexpected events, or generally speaking, stimuli that cannot be predicted based on previous experience elicit an orienting reaction. This allows the processing of this information in order to determine its relevance. To the extent that the irrelevant sound becomes more predictable based on previous information, the orienting reaction is assumed to attenuate, which fits quite nicely with the present results. Foreknowledge decreases the unpredictability of the auditory distractors, and should therefore lead to a reduction of their disruptive potential.

The present series of experiments has also led to the identification of boundary conditions for the effect of foreknowledge. First, disruption was only significantly reduced if the advance information was specific, but not if it was unspecific. This finding is fully in line with the predictions of the embedded-processes model (Cowan, 1995). Only stimulus-specific foreknowledge is helpful in establishing an internal representation of the upcoming auditory stimulation. This is already evident from previous findings showing that it is the specific content of the distraction, rather than distraction per se, that is disruptive for serial recall (e.g., Bell et al., 2012). This may also explain why coherent sentences have produced the largest foreknowledge effects in the present series of experiments. Advance information about the distractor material seems to only result in a significant reduction of the distractor effect when participants can effectively establish a stable internal representation of the distractor material that helps to reduce the material's unpredictability. Second, the effect of foreknowledge depends on the type of to-be-ignored auditory material. Disruption of coherent background speech was significantly reduced by foreknowledge. In contrast, there was only a non-significant tendency towards a reduction of interference when lists of one-syllable words were used as distractor material. When steady state sequences were used (i.e., lists consisting of repetitions of a single repeated distractor word), there was no evidence of foreknowledge effects. The simplest explanation of this pattern of findings is that the effect of foreknowledge depends on the complexity of the distractor material. Consistent with previous studies, coherent speech proved to be the type of distractor material that caused the largest interference effect, providing ample opportunity for improvement by foreknowledge. By contrast, foreknowledge can reduce only little of the auditory distractor's unpredictability if the sequences are very predictable from the outset such as steady state sequences and changing state sequences in which many stimulus features are held constant. Steady state sequences typically fail to significantly disrupt serial recall compared to a quiet control condition (Jones, 1994; Jones & Macken, 1993; Jones et al., 1992; but see LeCompte, 1995). Thus, there is practically no potential for foreknowledge to benefit performance. Steady state sequences are also extremely predictable. In the present experiments, for instance, whenever the second spoken word was the same as the first spoken word participants would immediately know that 16 more repetitions of exactly this word were to follow. Therefore, the amount of additional information that a transcript of a steady state sequence can provide is negligible.

An interesting aspect is that neither the foreknowledge provided in the present Experiments 1 and 2 nor the repeated presentation of upcoming distractors in previous studies (Bell et al., 2012; Röer et al., 2013, 2014a, 2014b) were sufficient to eliminate the disruption caused by auditory distractors completely. At fist sight, this aspect may seem counterintuitive from the perspective of an attentional explanation of auditory distraction which may be interpreted to imply that there should be a point at which distractors no longer attract any attention at all. However, this view would be too simplistic. First, the neural representation of the auditory distractor material based on the advance information can hardly be perfect, which means that the distraction effect should only be reduced to a certain degree, and not be eliminated completely. Second, as we have argued before (cf. Marsh et al., 2014; Röer et al., 2014a), there has to be a basic call for attention process enabling the organism to detect an auditory stimulus and to compare it to an existing neural model, even when a full attention switch to the auditory modality is then denied (see also Campbell et al., 2003). This basic process will necessarily consume some degree of cognitive resources, causing a certain level of interference which cannot be reduced. In essence, then, the beneficial effect of foreknowledge seems to depend on the amount of unpredictability that can effectively be reduced by the specific advance information presented to the participants. Thus, foreknowledge effects can be expected whenever there is a high degree of unpredictability inherent in the distractor material that can be effectively communicated prior to each trial, and converted into a stable internal representation of the upcoming sound.

At first sight, the present results seem incompatible with the duplex-mechanism account of auditory distraction (Hughes, 2014), which claims that the auditory deviant effect and the changing state effect are caused by different mechanisms. More specifically, changing state disruption is assumed to be the consequence of a conflict between relevant and irrelevant order information, and should be immune to foreknowledge manipulations (cf. Hughes et al., 2013). This is inconsistent with the results reported here, which demonstrate that specific foreknowledge about imminent speech reduces its disruptive potential to a considerable degree. Thus, the present findings represent a challenge for the strict functional dissociation that the account proposes. Other aspects of the present results seem to be more in line with the predictions of the duplex-mechanism account. It is possible to significantly reduce auditory interference by specific foreknowledge, but at the same time the distractor sequences continue to disrupt performance to some degree. It is this aspect that fits quite nicely with the general idea behind the duplex-mechanism account (Hughes, 2014; Hughes et al., 2013) to differentiate between a resistible (attentional distraction) and an indomitable form of auditory distraction (automatic interference).

To accommodate the data reported here, the duplex-mechanism account would have to be revised. This revision would have to take into account that attentional distraction may play a role not only in the auditory deviant effect, but in changing state distraction by complex irrelevant sound (coherent speech) as well. Such a modification seems plausible given that cognitive manipulations are rarely process-pure. Conceivably, auditory sequences may capture attention, and may be obligatorily processed to some extend, so that some part of the distraction effect may be relatively open to modulation by top-down processes while a residual amount of basic interference may be very hard to overcome. One could assume, for instance, that sentences are not only more appropriate for forming a stable internal representation than lists of randomly assembled words, but that sentences also contain features which cause attentional distraction that are not present in random word lists. For instance, sentences contain a syntactical structure of which one could assume that it causes attentional distraction, for whatever reason. Once that syntactical structure is known, attentional distraction can be overcome, and performance improves up to the limit set by the automatic interference caused by the preattentional seriation of the to-be ignored auditory stream. Hence, the present finding could be integrated in the duplex-mechanism account of auditory distraction by assuming that disruption by changing-state sequences consisting of highly predictable lists of one-syllable words is due to automatic interference while disruption by background speech consisting of coherent sentences is, to a considerable degree, caused by attentional disruption. This modified version of the duplex-mechanism account would be able to explain why foreknowledge reduces disruption by coherent speech in Experiments 1-2, but fails to have a significant effect on the changing-state effect in Experiment 4. Note that this version of the duplex-mechanism account differs from the original version of the account, which assumes that disruption by continuously changing sounds is solely due to automatic interference, whereas attentional capture is restricted to situations where sounds grossly violate an auditory rule, or possess personal relevance (Hughes, 2014). The present study suggests that naturalistic distractor material such as coherent speech captures attention, and that disruption by this material is, at least to some degree, under cognitive control. One implication of this view is that results obtained with the stimulus material commonly used in studies on auditory distraction—that is, lists of changing one-syllable words—cannot be readily generalized to more complex material such as coherent distractor speech.

To summarize, the present series of experiments adds to a growing literature demonstrating the impact of expectancy-based processes on the disruption by auditory distractors. Nöstl et al. (2012), for instance, demonstrated that the "unexpectedness" of a distractor (i.e., the degree to which it deviates from an expected pattern) can be a more important determinant of interference than local changes in stimulus characteristics (see also Parmentier et al., 2011). Extending these findings, the present series of experiments demonstrates that the effects of expectations are not limited to being detrimental for performance if they are violated, but instead can also be beneficial if they reduce the uncertainty about upcoming distractors. Most interestingly, this benefit does not depend on the physical preexposure to the distractor sequence, but can also be observed when the information about the distractor is presented in a different modality.

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Figure Captions

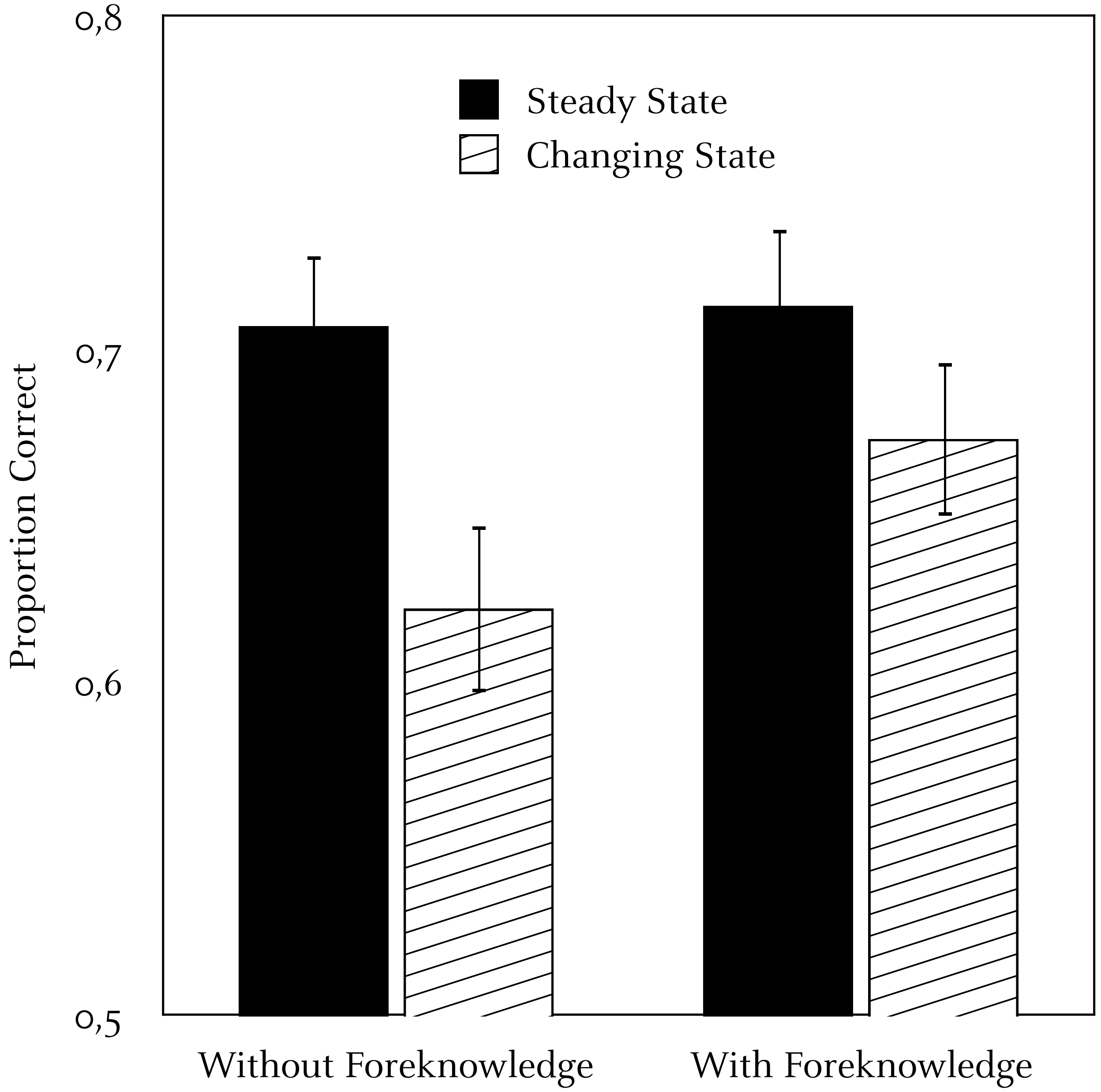
Figure 1: Proportion of correct responses as a function of auditory distractor condition and foreknowledge in Experiment 1. The error bars depict the standard errors of the means.

Figure 2: Proportion of correct responses as a function of auditory distractor condition and foreknowledge in Experiment 2. The error bars depict the standard errors of the means.

Figure 3: Proportion of correct responses as a function of auditory distractor condition and foreknowledge in Experiment 3. The error bars depict the standard errors of the means.

Figure 4: Proportion of correct responses as a function of auditory distractor condition and foreknowledge in Experiment 4. The error bars depict the standard errors of the means.

Figure 1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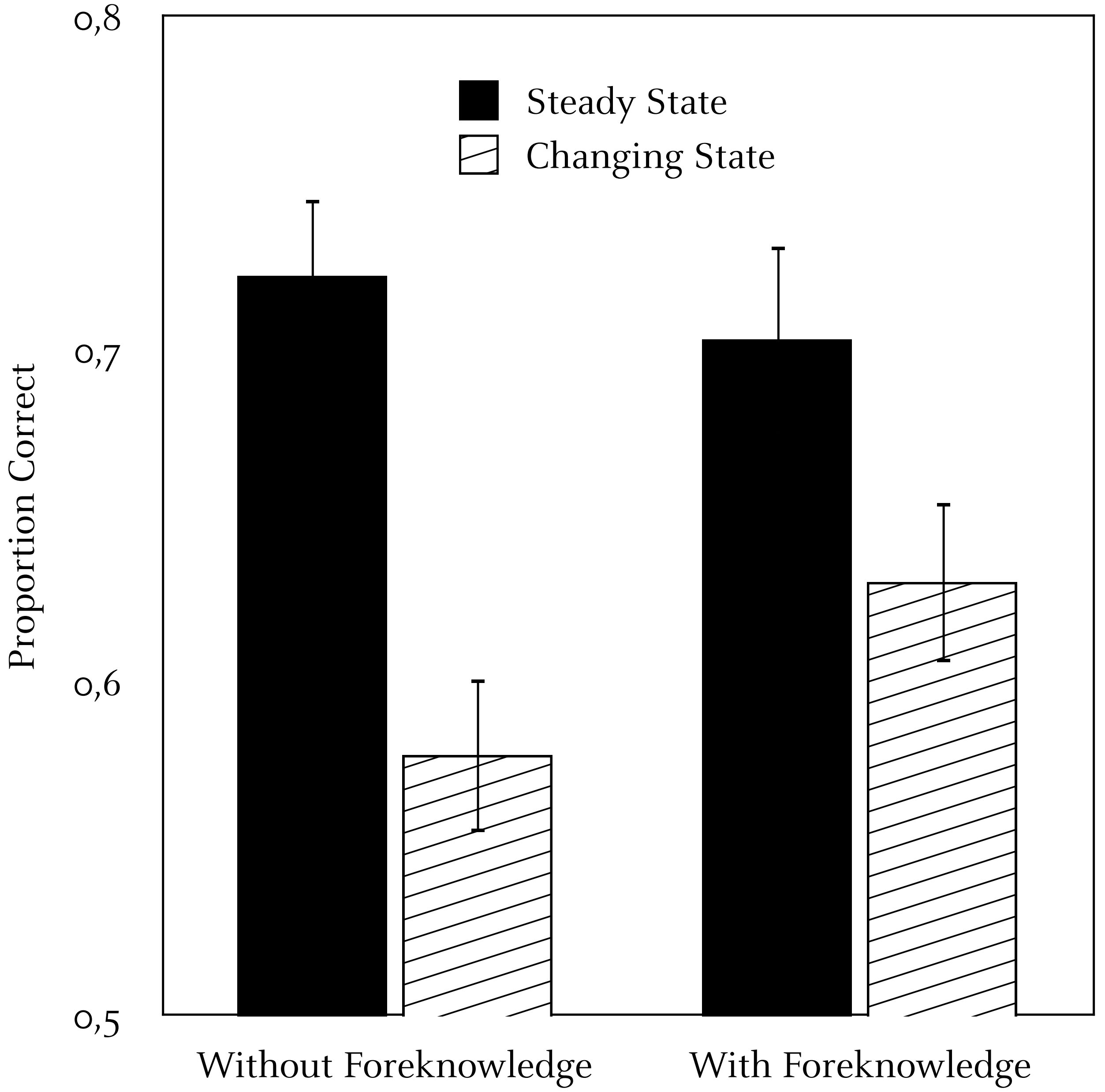
Proportion Correct
Steady State
Changing State
Without Foreknowledge
With Foreknowledge

Figure 2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Proportion Correct
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Changing State
Without Foreknowledge
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Figure 3

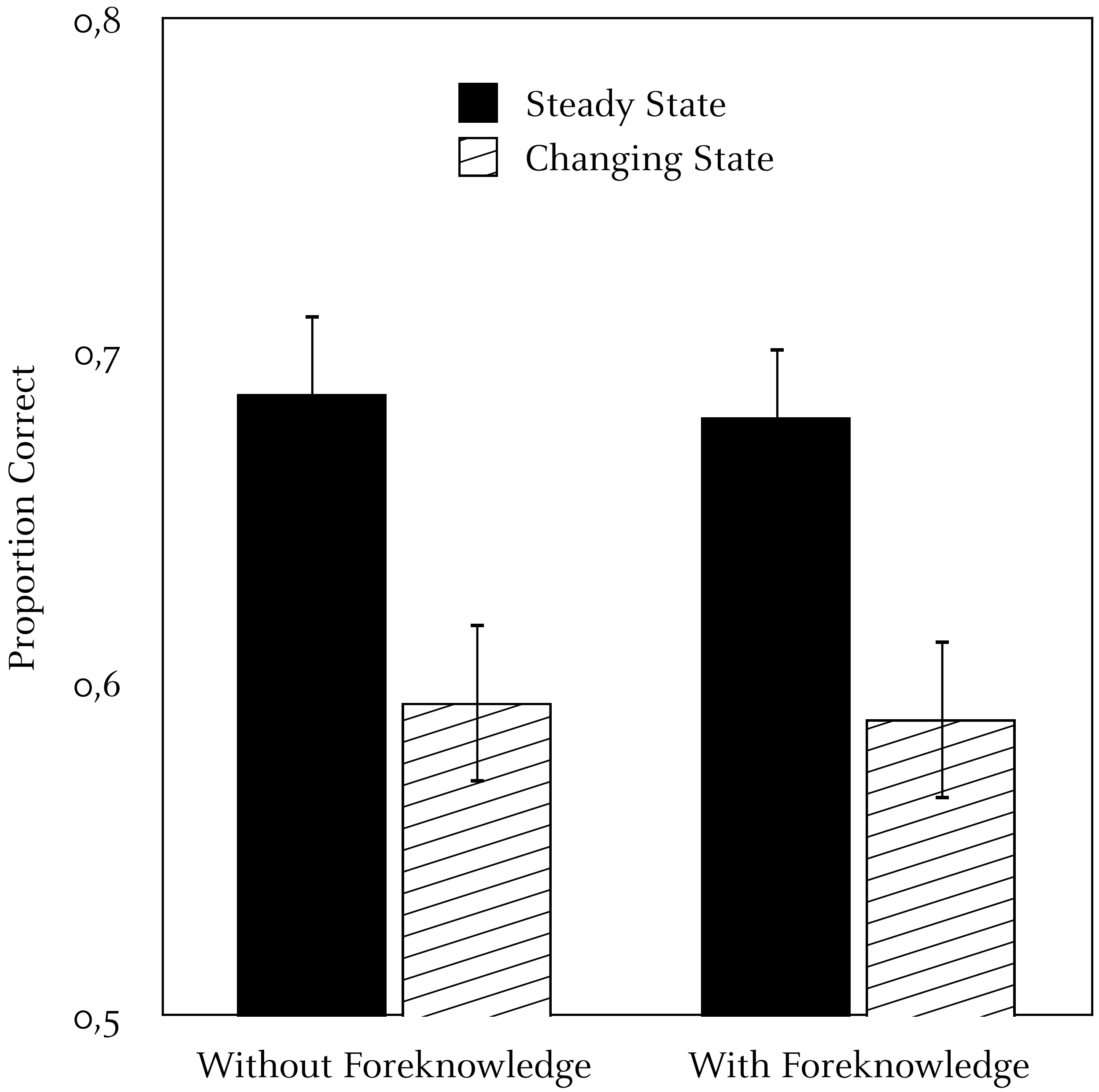
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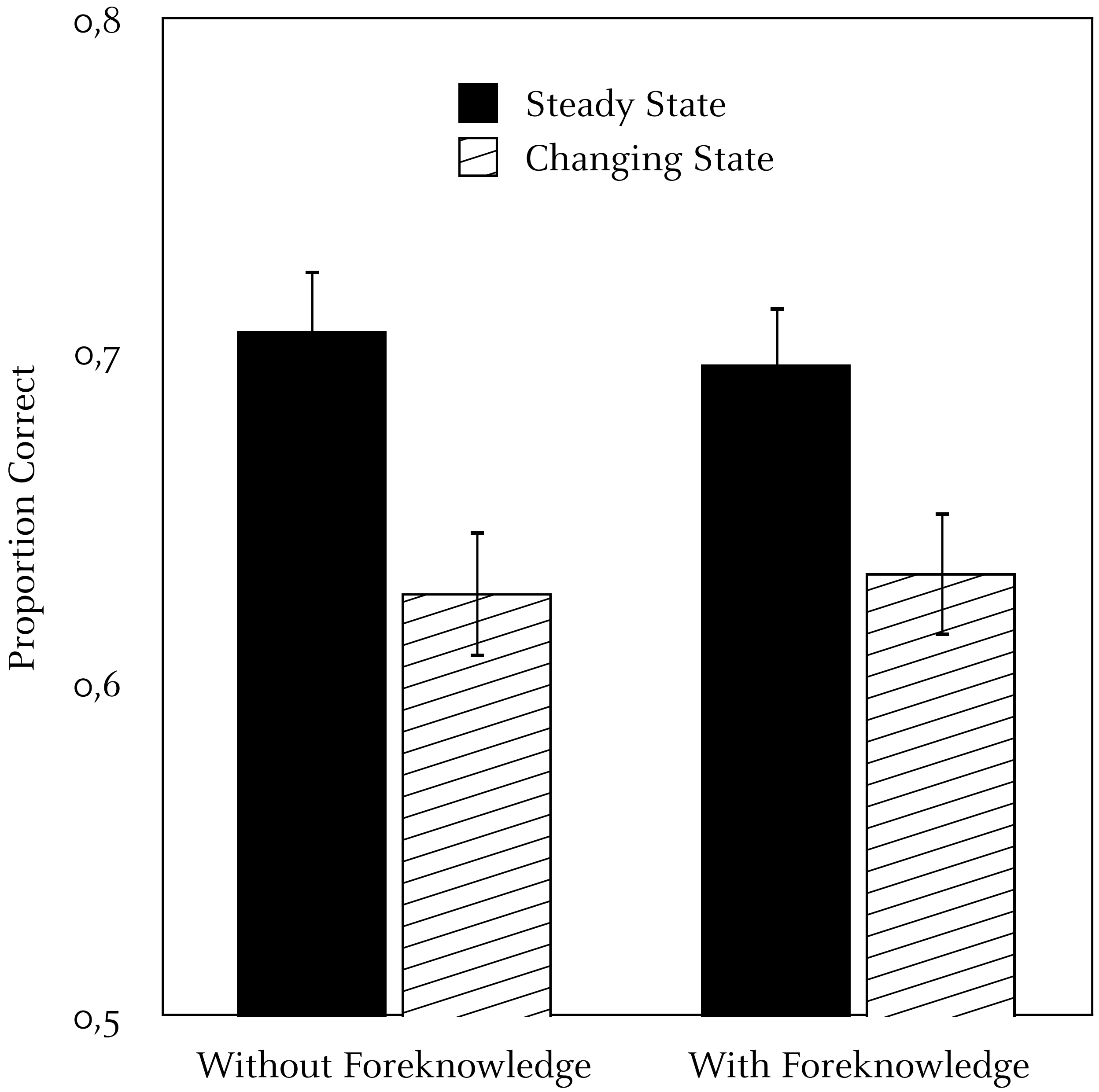
Figure 4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