Attentional capture by taboo words: A functional view of auditory distraction

Jan P. Röer

Ulrike Körner

Axel Buchner

Raoul Bell

Heinrich-Heine-Universität Düsseldorf

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Corresponding Author:

Jan Philipp Röer

Institut für Experimentelle Psychologie

Heinrich-Heine-Universität Düsseldorf

40225 Düsseldorf, Germany

E-Mail: jan.roeer@hhu.de

Abstract

It is well established that task-irrelevant, to-be-ignored speech adversely affects serial short-term memory for visually presented items compared to a quiet control condition. However, there is an ongoing debate about whether the semantic content of the speech has the capacity to capture attention and to disrupt memory performance. In the present paper, we tested whether taboo words are more difficult to ignore than neutral words. Taboo words or neutral words were presented as (1) steady state sequences in which the same distractor word was repeated, (2) changing state sequences in which different distractor words were presented, and (3) auditory deviant sequences in which a single distractor word deviated from a sequence of repeated words. Experiments 1 and 2 showed that taboo words disrupted performance more than neutral words. This taboo effect did not habituate and it did not differ between individuals with high and low working memory capacity. In Experiments 3 and 4, in which only a single deviant taboo word was presented, no taboo effect was obtained. These results do not support the idea that the processing of the auditory distractors' semantic content is the result of occasional attention switches to the auditory modality. Instead, the overall pattern of results is more in line with a functional view of auditory distraction, according to which the to-be-ignored modality is routinely monitored for potentially important stimuli (e.g., self-relevant or threatening information), the detection of which draws processing resources away from the primary task.

Keywords: emotion, threat avoidance, working memory, semantic interference, irrelevant speech

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In a situation in which different sources of information come into conflict for processing, the attentional system has to select information that is relevant for the pursuit of current and long-term behavioral goals, and ignore information that is irrelevant. This attentional selectivity involves the challenge of balancing two opposing aims. Relevant information can be processed more thoroughly when fewer resources are devoted to other sources of information. At the same time, task-irrelevant channels cannot be blocked off completely, otherwise stimuli that are potentially important such as self-relevant or threatening information would not be detected. Thus, some resources must be devoted to the processing of task-irrelevant information. On the positive side, this processing enables the detection of important stimuli in the to-be-ignored channel, on the negative side, it may draw processing resources away from the primary task.

A classic example of the negative effect of task-irrelevant information on cognitive performance is the disruption of working memory by to-be-ignored speech (e.g., Colle & Welsh, 1976; Jones, Madden & Miles, 1992; Salamé & Baddeley, 1982). The standard paradigm to measure disruption by irrelevant speech is serial short-term memory for visually presented items. In this task, participants are shown a list of items either in silence or accompanied by auditory distractor speech. Relative to a silent condition, fewer items are recalled correctly when irrelevant speech is played during item presentation or after item presentation during a retention interval (Jones et al., 1992; Röer, Bell & Buchner, 2014a). There is broad consensus that this irrelevant speech effect is not due to an increase in arousal: Sounds are usually played at a moderate intensity, and it was demonstrated repeatedly that the magnitude of disruption is not sensitive to the auditory distractor's sound level as long as it is 40 dB(A) or above (e.g., Ellermeier & Hellbrück, 1998).

One of the most important determinants of interference is the acoustic variability of the distractor sequence (Ellermeier & Zimmer, 2014). For instance, sequences comprising many different distractor items (e.g., "a, b, c, d, e, f, g, h") or two alternating distractor items (e.g., "a, b, a, b, a, b, a, b") typically have a large disruptive effect on serial recall (e.g., Jones et al., 1992; Röer, Bell, Dentale & Buchner, 2011). It has been shown frequently that natural speech and sequences that resemble speech in their acoustic properties (i.e., a high amount of unpredictable changes in the

amplitude and frequency spectrum) are particularly disruptive (Röer, Bell & Buchner, 2014b, 2015; Schlittmeier, Weißgerber, Kerber, Fastl & Hellbrück, 2012; Schlittmeier, Weisz & Bertrand, 2011). In contrast, steady state sequences such as repeated distractor items (e.g., "a, a, a, a, a, a, a, a") or continuously presented noise are said to produce only little or no interference compared to a quiet control condition (Jones et al., 1992). The increase in disruption by changing state sequences relative to steady state sequences is referred to as the changing state effect (Beaman & Jones, 1997; Jones et al., 1992).

Another important determinant of interference is the extent to which the distractor items violate recent auditory regularities. Sequences containing a single distractor item that deviates from an otherwise repetitive sequence (e.g., "a, a, a, a, b, a, a, a") are known to cause a pronounced decrement in serial recall relative to sequences without such a deviant. Auditory deviants could be, for example, a different distractor in a sequence of repeated distractors (Röer, Bell, Marsh & Buchner, 2015), a distractor that is spoken by a different voice (Sörqvist, 2010a), or a distractor that is presented with a short time lag (Hughes, Vachon & Jones, 2005). Irregularities that occur across experimental trials produce effects that are similar to those of within-trial irregularities. When after five presentations of the same irrelevant speech sequence there is a change from a female voice to a male voice, or vice versa, a marked drop in serial recall performance can be observed (Vachon, Hughes & Jones, 2012; see also Röer, Bell & Buchner, 2014a). The increase in disruption by auditory deviant sequences relative to steady state sequences is referred to as the auditory deviant effect (Hughes et al., 2005; Vachon et al., 2012).

In the present study, we tested a functional view of auditory distraction according to which the cognitive system's openness to the processing of task-irrelevant information serves the function of alerting individuals to potentially relevant information in the to-be-ignored channel. Theories that assume prioritized processing of emotional information (e.g., Bower, 1992; Cowan, 1999; MacKay et al., 2004; Mather & Sutherland, 2011) propose that the attentional system comes with a built-in mechanism that is designed to detect and react to stimuli that are of potential relevance for the individual. Bower (1992), for example, writes that "the organism should have some sensors that monitor its internal and external environment for signals implicating its important concerns, and an ability to interrupt or suspend an ongoing plan in order to deal with an urgent crisis, whether positive or negative" (p. 4). From a functional perspective, it can be argued that (1)

the semantic content of task-irrelevant stimuli should always be processed to some extent in order to determine its relevance for the individual, and that (2) relevant stimuli such as threatening information in the to-be-ignored channel have the potential to capture and hold attention and should not remain undetected.

This view can be contrasted with an automatic account of interference which construes the disruptability of working memory performance by irrelevant speech as a shortcoming of the cognitive system (Marsh, Hughes & Jones, 2009; Marsh, Perham, Sörqvist & Jones, 2014). According to this second account, the disruptive effect of an irrelevant speech sequence on serial recall should only be determined by changes in the amplitude and frequency spectrum, and it should be independent of its semantic content (cf. Beaman & Jones, 1997). Interference is assumed to be the result of the preattentional processing of stimulus features that occurs because the cognitive system is leaky and cannot block off the processing of the to-be-ignored stimuli completely. In consequence, processing may "spill over" to the auditory distractors, because the routines that are necessary to process task-relevant information also inadvertently process task-irrelevant information. This view predicts that the semantic processing of irrelevant speech should not interfere with the primary task unless this task requires semantic processing as well.

Within the irrelevant sound literature, the question of semantic processing of the auditory distractors has remained a controversial topic. In several early studies, semantic content had no effect on the auditory distractors' potential to disrupt working memory performance. For instance, speech played forward and speech played backward were found to be equally disruptive (Jones, Miles & Page, 1990; Röer et al., 2014a) as were distractor words from the same category as the to-be-remembered items and distractor words from a different category (Buchner, Irmen & Erdfelder, 1996; Marsh et al., 2009; but see Bell, Mund & Buchner, 2011). Against this backdrop, in a number of recent publications the prevailing view is that the disruptive effect of irrelevant speech on serial recall is largely independent of its semantic content (Klatte, Lachmann, Schlittmeier & Hellbrück, 2010; Marsh et al., 2014; Sörqvist, 2010b). Sörqvist (2010b, p. 218), for example, concludes that "the semantic meaning of the sound seems to add nothing to the disruptive effects of speech on serial recall". The empirical situation, however, is a little bit more ambiguous than this conclusion suggests. Low-frequency words, for instance, have been shown to be more disruptive to serial recall than high-frequency words (Buchner & Erdfelder, 2005; but see

Elliott & Briganti, 2012). Larger irrelevant speech effects were also reported for positively and negatively valent words (Buchner, Mehl, Rothermund & Wentura, 2006; Buchner, Rothermund, Wentura & Mehl, 2004) and for sentences containing one's own name compared to that of a yoked-control partner (Röer, Bell & Buchner, 2013).

This pattern of results can be interpreted in two very different ways. One possibility is that irrelevant speech is always processed semantically to some extent to detect stimuli that are of potential relevance for the individual. Once a relevant stimulus is detected (e.g., self-relevant or threatening information), attention is shifted to the nominally irrelevant channel and, as a consequence, performance in the primary task suffers. Distractor words that are semantically similar to the items (Buchner et al., 1996; Marsh et al., 2009) or distractor words that are infrequent in the language (Elliott & Briganti, 2012) are probably not relevant enough to capture and hold a significant amount of attentional resources, particularly in a controlled laboratory setting in which the participants have been instructed to ignore all sounds that they may hear. In contrast, the presentation of behaviorally more relevant stimuli such as the own name compared to the name of a yoked-control partner (Röer et al., 2013) resulted in a pronounced performance decrement. However, the own name is an excessively repeated and highly overlearned stimulus and, thus, it may represent a special case. This is illustrated by the fact, for example, that it is typically detected even without elaborated semantic processing. The auditory presentation of one's own name during sleep triggers a differential brain response as compared to other names (Perrin, Garcia-Larrea, Mauguiere & Bastuji, 1999). Therefore it may be argued that the organism responds primarily to its phonologic rather than its semantic characteristics.

An alternative possibility to interpret the results is that the semantic content only affects performance when the primary task requires semantic processing as well. Marsh and colleagues (2014, p. 1297) argue that "on the rare occasions in which lexical factors associated with irrelevant speech influence visual-verbal serial recall, they do so because semantically rich material, such as words, are presented for recall, thereby recruiting the speech production system". Indeed, in most studies yielding evidence for semantic interference the to-be-remembered items were words and not digits or consonants (Buchner & Erdfelder, 2005; Buchner et al., 2006; Buchner et al., 2004). Although this does not always seem to be the case—Elliott and Briganti (2012) found no evidence for semantic interference when words had to be recalled—semantically rich to-be-remembered

items may increase the demands on semantic processing routines. If that were the case and semantic interference was determined by the amount of semantic processing that the relevant information receives, then semantic interference should be limited to situations in which the primary task relies heavily on semantic processing. Serial recall of visually presented digits—which are "by design impoverished in terms of their semantic content" (Marsh et al., 2014, p. 1298)—should then be unaffected by the content of irrelevant speech.

To put these two conflicting accounts to an empirical test, we investigated whether taboo words are more difficult to ignore than neutral words. Taboo words are high priority stimuli for which fast and focused responding is critical because they signal a potentially threatening event (cf. Mather & Sutherland, 2011). They are known to capture and hold attention, for example, in the context of the emotional Stroop effect, which refers to the phenomenon that participants take longer to name the color of taboo words than that of neutral words (Siegrist, 1995; see also Dhooge & Hartsuiker, 2011). Presenting auditory taboo words allowed us to test whether auditory distractors in the irrelevant speech paradigm are routinely processed semantically. If this were the case, then presenting a taboo word, that is, a stimulus that signals a threatening or arousing event should alert the attentional system to allocate further processing resources to the auditory modality away from the primary task, which should result in a decrease in performance in the condition with taboo words relative to a control condition with neutral words. If, in contrast, the demands of the primary task determine the degree to which the irrelevant speech is processed semantically (cf. Marsh et al., 2014), then the serial recall of visually presented digits should be independent of the content of the auditory distractors, because the primary task does not require semantic processing and task-relevant and task-irrelevant information are presented in different modalities and, thus, the to-be-ignored, auditory channel can be efficiently blocked off from semantic processing.

Ethics statement

The study was approved by the ethics committee of the Faculty of Mathematics and Natural Sciences at Heinrich Heine University Düsseldorf. Participants signed informed consent before starting the experiment.

Experiment 1

Method

Participants

Sixty Heinrich Heine University students (40 women, *M* of age = 24) were paid for participating or received course credit. All participants were fluent German speakers and reported normal hearing and normal or corrected-to-normal vision.

Materials

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

Auditory distractors were 180 German two-syllable words, half of which were neutral words and half were taboo words. The number of nouns, verbs, and adjectives was the same for both categories, and neutral and taboo words were equally frequent according to the German language corpus of Leipzig University, available from http://wortschatz.informatik.uni-leipzig.de (last retrieved on 2015 Feb 25). The taboo ratings were assessed in an independent norming study (N = 26). Participants rated each word by clicking on a 9-point scale that ranged from "not at all taboo" (1) to "totally taboo" (9). As expected, a significantly higher rating was given to the taboo words (M = 5.5) than to the neutral words (M = 1.3), $t(25) = 35.00$, $p < .001$, d = 5.2, 95% CI [3.90, 4.37]. The complete set of distractor words with number of occurrences, frequency class, and taboo rating are reported in the online supplementary material.

The auditory distractors were spoken by a female computer voice ("Anna") using Apple's text-to-speech software. All sounds were presented binaurally at about 60 dB(A).

Procedure

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

A training phase consisted of four quiet trials to familiarize participants with the serial recall task. The experimental phase consisted of ten trials in each of the five sound conditions (quiet, steady state neutral, steady state taboo, changing state neutral, changing state taboo), which were presented in random order. In steady state trials the same distractor word was presented eight times (e.g., "soda, soda, soda, soda, soda, soda, soda, soda", or "asshole, asshole, asshole, asshole, asshole, asshole, asshole, asshole"); note that steady state trials are typically composed of one-syllable words, numbers or spoken consonants whereas here we use this terminology to refer to repetitions of identical two-syllable words. In changing state trials eight different words from the same category (neutral or taboo) were presented (e.g., "cedar, tractor, backrest, zebra, stapler, seahorse, rhombus, tendril", or "sucker, dirtbag, dildo, nipples, petting, swinger, blowjob, darkroom"). Words were drawn randomly without replacement from the distractor set, so that no two trials comprised the same word. Each distractor sequence lasted eight seconds. The to-be-ignored speech was only played while the to-be-remembered digits were presented. Immediately after each trial, participants recalled as many of the visually presented digits as possible. A digit at a particular serial position could be omitted by pressing an "I don't know" button. Participants were required to recall the digits in forward order. There was no possibility to correct a prior entry. Feedback was given after each trial.

It took the participants approximately 22 minutes to complete the experiment. Afterwards they were offered an explanation about the purpose of the study.

Design

A repeated measures design was used with sound condition (quiet, steady state neutral, steady state taboo, changing state neutral, changing state taboo) and ordinal trial position (1-10) as the independent variables and serial recall performance as the dependent variable. Answers were scored according to a strict serial recall criterion (i.e., to-be-remembered numbers were only scored as correct when they were reproduced in the exact serial position.

If auditory taboo words are more difficult to ignore than neutral words, then they should produce a larger changing state irrelevant speech effect (i.e., increased disruption by changing state sequences relative to steady state sequences). Thus, of primary interest is the comparison between the changing state neutral condition and the changing state taboo condition. Given $\alpha = \beta = .05$, and the assumption that the average population correlation between the two levels of the repeated measures factor is $\rho = .5$, a taboo effect of size $f = 0.23$ could be detected. All power calculations were conducted using G*Power (Faul, Erdfelder, Lang & Buchner, 2007). The level of α was set to .05 for all analyses, and η_p^2 is reported as a measure of effect size.

Results

Figure 1 illustrates the serial recall performance as a function of sound condition (quiet, steady state neutral, steady state taboo, changing state neutral, changing state taboo). A 5×10-MANOVA yielded significant main effects of sound condition, $F(4,56) = 40.04$, $p < .001$, $\eta_p^2 = .74$, and ordinal trial position, $F(9,51) = 5.39$, $p < .001$, $\eta_p^2 = .49$, but no interaction of these variables, $F(36,24) = 0.62$, $p = .906$, $\eta_p^2 = .48$. Orthogonal contrasts revealed that the typical irrelevant speech effect could be observed, $F(1,59) = 97.08$, $p < .001$, $\eta_p^2 = .69$, that is, recall performance was reduced in the distractor conditions relative to the quiet condition. When the four distractor conditions were compared in a 2 × 2 MANOVA there were significant effects of changing state, $F(1,59) = 69.90$, $p < .001$, $\eta_p^2 = .54$, and of taboo, $F(1,59) = 11.16$, $p = .001$, $\eta_p^2 = .16$, which were qualified by an interaction between changing state and taboo, $F(1,59) = 6.84$, $p = .011$, $\eta_p^2 = .10$. A taboo effect was only observed when the changing state conditions were compared, $t(59) = 3.98$, $p < .001$, $\eta_p^2 = .21$, 95% CI [0.02, 0.07], but not when the steady state conditions were compared, $t(59) = 0.43$, $p = .677$, $\eta_p^2 < .01$, 95% CI [-0.02, 0.03].

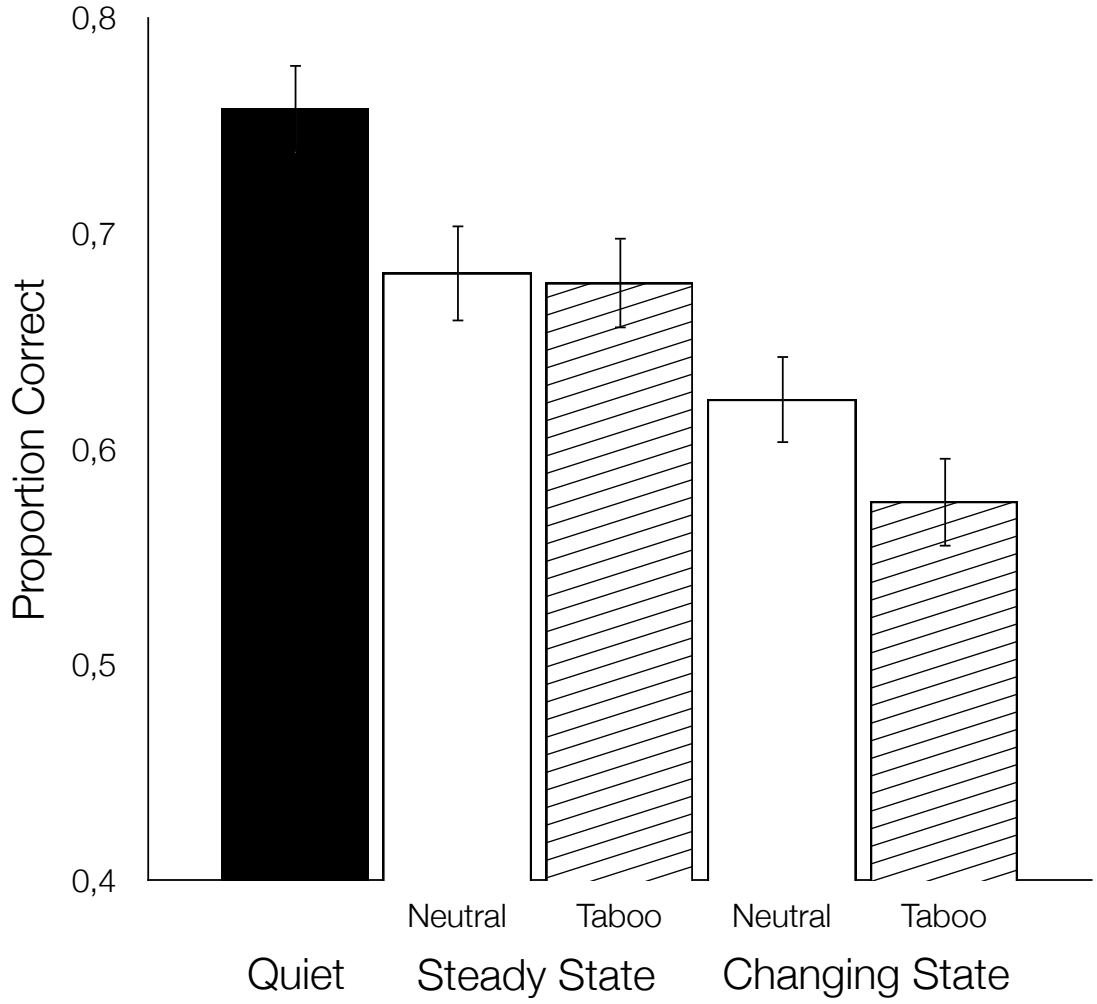

Figure 1: Recall performance as a function of sound condition (quiet, steady state neutral, steady state taboo, changing state neutral, changing state taboo) in Experiment 1. The error bars depict the standard errors of the means.

We also analyzed to what extent the changing state taboo effect was reduced as a function of ordinal trial position over the course of the experiment. A reduced disruption of taboo sequences relative to neutral sequences after repeated exposure would be evidence of habituation. There was, however, no interaction between the ordinal trial position variable and the variable contrasting the changing state neutral condition and the changing state taboo condition, $F(9,51) = 1.08$, $p = .392$, $\eta_p^2 = .16$. Participants' ability to ignore auditory taboo words did not improve over the course of the experiment any more than their ability to ignore neutral words. In other words, the taboo effect did not habituate.

Discussion

In Experiment 1, task-irrelevant taboo words were more difficult to ignore than task-irrelevant neutral words. When a sequence of taboo words was played, participants made significantly more errors in serial recall than when a sequence of neutral words was played. This is clear evidence that the content of the auditory distractors can have a distinct effect on how disruptive irrelevant speech is to working memory performance even though the primary task (i.e., the serial recall of visually presented digits) made only minimal, if any, demands on semantic processing (cf. Marsh et al., 2014). This finding is inconsistent with the interpretation that the content of irrelevant speech only interferes with the primary task when that task involves semantic processing, some of which may 'spill over' to the processing of the distractors. Instead, the semantic content of the distractors seems to have been routinely processed. Taboo words are readily detected in the ignored auditory channel and they have the potential to capture attention. These results are in line with a functional account of auditory distraction, according to which performance decrements occur because the nominally irrelevant material is monitored for behaviorally relevant stimuli. If such (threatening or emotionally arousing) stimuli are detected in the task-irrelevant channel, then they may grab attention at the expense of performance in the primary task.

Interestingly, our analyses revealed a significant interaction of semantic content (taboo, neutral) and distractor condition (steady state, changing state). There was a pronounced changing state taboo effect, but no steady state taboo effect. A repeated taboo word did not produce more disruption than a repeated neutral word. From the outset, it was unclear whether there would be such an interaction, or not. To explain this finding, one may assume that taboo words attract attention because of their word-specific meaning and that each taboo word triggers a unique emotional response, which habituates with repeated presentation (cf. MacKay et al., 2004). Under this assumption, a sequence comprising different taboo words should produce marked disruption because each words draws attentional resources away from the serial recall task. A sequence of repeated taboo words, by contrast, only triggers a single response at the beginning of the encoding phase, which is why the amount of attentional capture should be comparatively small and the detrimental effect on serial recall should be minor because at this point working memory is low. If taboo words attract attention because of their specific meaning, there should be an interaction of semantic content and distractor condition, which was confirmed by the present results. A large

taboo effect for changing state sequences, but no taboo effect for steady state sequences suggest that it is indeed the specific meaning of the particular word that captures attention rather than an expectancy violation at a more global level (i.e., taboo words are rather unexpected in the context of a psychological experiment at a university). This interpretation is in line with findings obtained with the emotional Stroop paradigm, in which participants took longer to name the color of new taboo words than that of a repeated taboo word, which led to the conclusion that taboo words trigger a unique emotional reaction which habituates with stimulus repetition (MacKay et al., 2004).

The functional explanation of the taboo effect outlined above implies that the semantic content of the auditory distractors is always monitored for the occurrence of behaviorally relevant stimuli in the to-be-ignored channel. If such stimuli are detected (e.g., threatening information), further processing resources are allocated to the auditory modality, away from the primary task. However, an alternative interpretation of the results is also conceivable. It could be, for instance, that the taboo effect is simply a by-product of an error-prone attentional system. Specifically, some participants may fail to maintain focal attention on the task-relevant, visual information. The focus of attention may occasionally wander away from the visual modality to the auditory distractor material, as a result of which the semantic content of the taboo words is processed. If the taboo effect is indeed due to such a reduced ability to constrain attention to the primary task, we would expect it to be more pronounced for individuals with low working memory capacity. Sörqvist (2010a), for example, demonstrated that individual differences in working memory capacity reflected by operation span (OSPAN) task performance (cf. Turner & Engle, 1989) were associated with the susceptibility to the auditory deviant effect: Individuals with low working memory capacity were more distracted by auditory deviants than individuals with high working memory capacity. If the taboo effect is the result of occasional slips of attention, individuals with high working memory capacity should be able to maintain focal attention on the task-relevant, visual information, which should prevent semantic processing of the auditory distractors, and reduce or even abolish the taboo effect. Thus, the attentional slippage view predicts that the taboo effect should be more pronounced for individuals with low working memory capacity compared to individuals with high working memory capacity.

The functional view of auditory distraction, in contrast, makes no such prediction. The monitoring of aspects of the environment for potentially relevant information should be a necessity for all individuals; there is no reason why the monitoring should occur more frequently in individuals with low working memory capacity. In fact, not all studies have found that individuals with high working memory capacity are less disrupted by auditory distractors than individuals with low working memory capacity. For instance, there seems to be consensus that the changing state effect is unrelated to individual differences in working memory capacity (e.g., Beaman, 2004; Elliott & Briganti, 2012; Sörqvist, 2010a, 2010b). Furthermore, a recent study examining the relationship between working memory capacity and the disruption of serial recall by changing and deviant speech sounds (Röer, Bell, Marsh, et al., 2015) found that the auditory deviant effect was equally unrelated to working memory capacity in both young and old adults. Thus, it cannot be taken for granted that individual differences in working memory capacity are related to the susceptibility to auditory distraction by taboo words.

Experiment 2 was a direct replication of Experiment 1. In addition, working memory capacity was measured using the OSPAN task and the sentence span task to explore the degree to which the taboo effect is modulated by individual differences in working memory capacity.

Experiment 2

Method

Participants

Seventy-four Heinrich Heine University students (50 women, *M* of age = 24) were paid for participating or received course credit. All participants were fluent German speakers and reported normal hearing and normal or corrected-to-normal vision.

Materials, Procedure, and Design

Experiment 2 was a direct replication of Experiment 1. In addition, individual working memory capacity was assessed using a German version of the OSPAN and sentence span tasks taken from the working memory test battery by Lewandowsky, Oberauer, Yang, and Ecker (2010). Two different working memory tasks were used in order to minimize task-specific variance asso-

ciated with individual WMC measures. In order to keep the Method section concise, only the key aspects of both working memory task are described here. A more detailed description can be found in Lewandowsky et al. (2010).

In each trial of the OSPAN task, participants were shown a mathematical equation (e.g. 6 + 2 = 7) that had to be evaluated for its correctness. Thereafter, a consonant was presented to be maintained for subsequent recall. The number of equations and to-be recalled consonants differed from four to eight, resulting in a total number of 15 trials. The sentence span task was equivalent to the OSPAN task, except that instead of equations the meaningfulness of sentences had to be judged. Participants completed both working memory tasks before the experiment started. Recall in both tasks was scored using the partial-credit load scoring (Conway et al., 2005), in which credit was given to each item that was recalled in the correct serial position. For each list length the proportions of remembered items were calculated and these proportion were averaged to obtain the OSPAN and sentence span score, respectively.

Results

The results almost perfectly mirror those of Experiment 1. Figure 2 illustrates the serial recall performance as a function of sound condition (quiet, steady state neutral, steady state taboo, changing state neutral, changing state taboo). A 5×10-MANOVA yielded significant main effects of sound condition, $F(4,70) = 26.76$, $p < .001$, $\eta_p^2 = .31$, and ordinal trial position, $F(9,65) = 3.94$, $p < .001$, $\eta_p^2 = .35$, but no interaction of these variables, $F(36,38) = 1.02$, $p = .475$, $\eta_p^2 = .49$. Orthogonal contrasts revealed the typical irrelevant speech effect, that is, decreased performance in the distractor conditions relative to the quiet control condition, $F(1,73) = 74.58$, $p < .001$, $\eta_p^2 = .50$. As in Experiment 1, a 2 × 2 MANOVA showed that there were significant effects of changing state, $F(1,73) = 73.83$, $p < .001$, $\eta_p^2 = .50$, and of taboo, $F(1,73) = 10.29$, $p = .002$, $\eta_p^2 = .12$. Again, the taboo effect was qualified by a significant interaction of both variables, $F(1,73) = 6.95$, $p = .010$, $\eta_p^2 = .09$. A taboo effect was only observed when the changing state conditions were compared, $t(73) = 4.12$, $p < .001$, $\eta_p^2 = .19$, 95% CI [0.02, 0.07], but not when the steady state conditions were compared, $t(73) = 0.44$, $p = .658$, $\eta_p^2 < .01$, 95% CI [-0.03, 0.02].

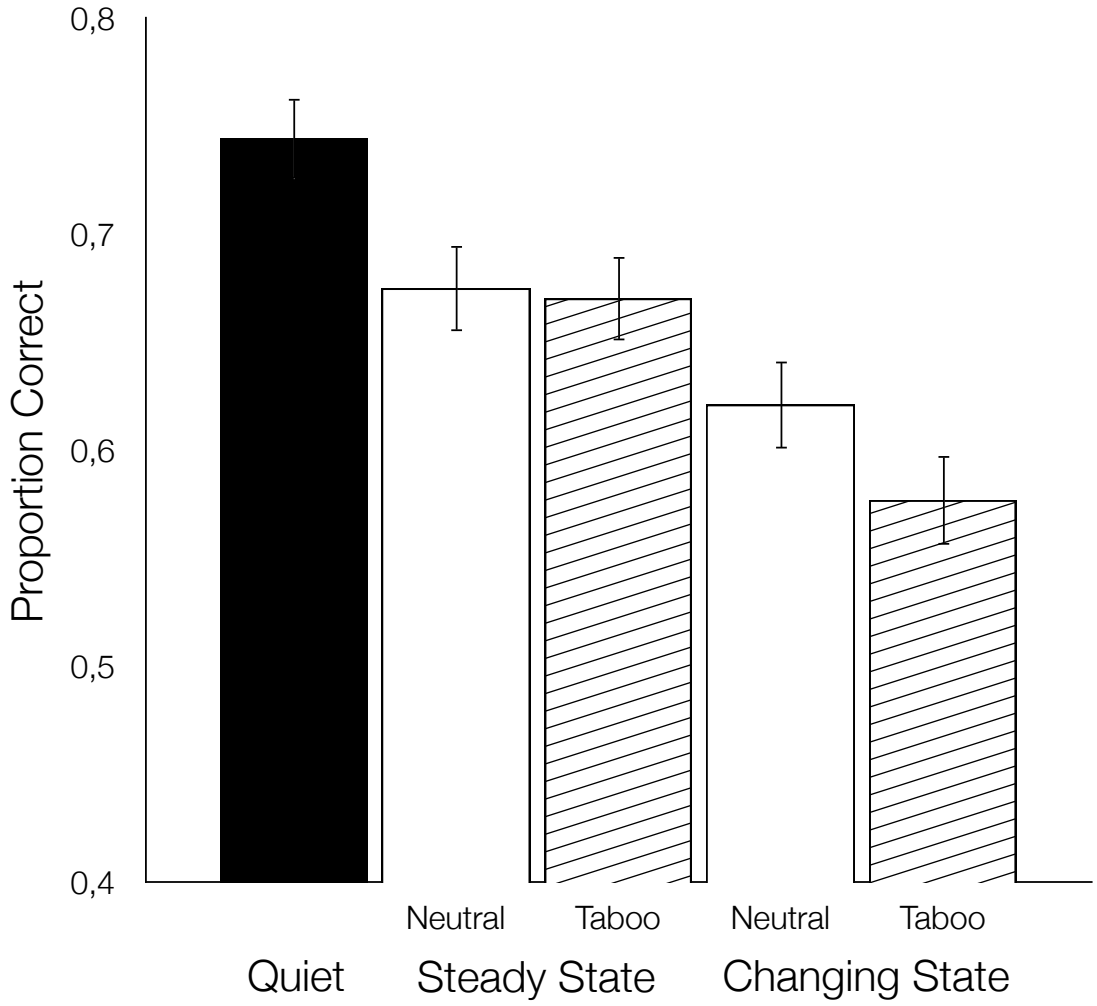

Figure 2: Recall performance as a function of sound condition (quiet, steady state neutral, steady state taboo, changing state neutral, changing state taboo) in Experiment 2. The error bars depict the standard errors of the means.

As in Experiment 1, the taboo effect did not habituate. There was no evidence of a reduced disruption after repeated exposure in form of an interaction between the ordinal trial position variable and the variable contrasting the changing state neutral condition and the changing state taboo condition, $F(9,65) = 1.08$, $p = .389$, $\eta_p^2 = .13$. We also analyzed to what extent the taboo effect was related to individual differences in working memory capacity. The taboo effect was calculated as the difference between the mean serial recall performance in the changing state neutral condition and the changing state taboo condition. As expected based on previous observations (cf. Lewandowsky et al., 2010) OSPAN scores ($M = .64$, $SD = .12$) and sentence span scores ($M = .83$, $SD = .13$) were highly correlated, $r = .995$, $p < .001$. Both measures of working memory capacity were also positively related to overall memory performance. Participants who scored high in

the OSPAN task showed better serial recall performance than those that scored low, $r = .282$, $p = .015$. The same was true for participants who scored high in the sentence span task, relative to those that scored low in this task $r = .261$, $p = .025$. Individual differences in working memory capacity, however, did not predict susceptibility to the taboo effect. The taboo effect was unrelated to individual differences in OSPAN performance, $r = .140$, $p = .234$, and unrelated to individual differences in sentence span performance, $r = .149$, $p = .204$.

Discussion

The most important finding of Experiment 2 is the replication of the taboo effect: Ignoring a sequence of auditory taboo words led to more errors in serial recall than ignoring a sequence of neutral words. As in Experiment 1, a significant interaction of semantic content and distractor condition was observed: There was a pronounced changing state taboo effect, but no steady state taboo effect, confirming once again that the taboo effect is due to the specific meaning of the words and not only due to an unspecific violation of expectancies. In Experiment 2, we specifically tested whether or not the taboo effect is related to individual differences in working memory capacity. According to a functional interpretation of the taboo effect, the content of the to-be-ignored auditory distractors should always be monitored to some extent in order to detect, and react to, relevant information with a full attention shift to the auditory modality. Taboo words, which are threatening and emotionally arousing and known for their attention-grabbing potential (Kensinger & Corkin, 2003; MacKay et al., 2004) should certainly fall into this category. This functional account was contrasted with an alternative, attentional slippage view, according to which the taboo effect is assumed to be a by-product of an error-prone attentional system. Under this assumption, interference occurs because participants fail to maintain focal attention on the task-relevant, visual information. The focus of attention may occasionally wander away from the visual modality to the auditory modality so that the semantic content of the distractors is processed inadvertently. In consequence, taboo stimuli may 'soak up' more processing resources than neutral stimuli. The attentional slippage view implies that the taboo effect should be more pronounced for individuals with low working memory capacity than for individuals with high working memory capacity. Inconsistent with this prediction, however, the taboo effect was unrelated to working memory capacity in Experiment 2.

Experiment 3 was designed to test the hypothesis that the taboo effect may be the consequence rather than the cause of attentional shifts to the auditory modality. It could be assumed that acoustic changes within the changing state sequence may sometimes capture attention, as a consequence of which the content of the auditory distractors is processed. If the distractor is a taboo word, a full attention shift to the auditory modality occurs. Similar explanations for semantic auditory distraction have been proposed in the literature (Escera, Yago, Corral, Corbera & Nunez-Pena, 2003; Parmentier, Turner & Perez, 2014). According to these accounts semantic distraction effects should become larger as a function of the degree to which the irrelevant speech captures attention. Parmentier et al. (2014), for example, asked participants to respond to the direction of visual arrows that pointed to the left or to the right with a button press on the computer keyboard while ignoring auditory distractor words. Participants were slower and more inaccurate when an incongruent auditory distractor was played (e.g., "left" when the arrow pointed to the right). This effect was more pronounced when the distractor word deviated from an otherwise repetitive sequence, which led Parmentier et al. (2014) to conclude that semantic processing and the subsequent interference increase as a function of the attention that the auditory stimulus captures. Such an account of semantic auditory distraction could be readily applied to the auditory taboo effect. Here, the assumption would be that the semantic content of the auditory distractors only affects performance when the distractors capture attention. If this assumption is correct, then a pronounced taboo effect would be predicted for auditory deviant stimuli, which are known to capture a large amount of attention away from the primary task (cf. Hughes, 2014; Röer, Bell & Buchner, 2015; Vachon et al., 2012).

If, however, taboo words have the capacity to capture attention on their own because the content of the auditory distractors is routinely monitored, a different prediction is possible. When auditory deviant words are used, attention is already captured by the violation of recent auditory regularities. In consequence, semantic content may only have a small effect because both auditory deviant taboo words and auditory deviant neutral words should produce a large amount of attentional capture from the outset. Thus, the taboo effect should become smaller or disappear.

Experiment 3

Method

Participants

Eighty-two Heinrich Heine University students (58 women, *M* of age = 25) were paid for participating or received course credit. All participants were fluent German speakers and reported normal hearing and normal or corrected-to-normal vision.

Materials, Procedure, and Design

All aspects were identical to Experiment 1 and 2, except that the changing state sequences were replaced by auditory deviant sequences. In these sequences, the same distractor word was presented four times, followed by a single presentation of a different distractor word, after which the original word was presented another three times (e.g., "soda, soda, soda, soda, crayon, soda, soda, soda", or "asshole, asshole, asshole, asshole, hardcore, asshole, asshole, asshole"). Auditory deviant sequences comprised either a repeated and a deviant neutral word or a repeated and a deviant taboo word. In total, there were five sound conditions: quiet, steady state neutral, steady state taboo, auditory deviant neutral, auditory deviant taboo.

Results

Figure 3 illustrates the serial recall performance as a function of sound condition. A 5×10-MANOVA yielded significant main effects of sound condition, $F(4,78) = 20.57$, $p < .001$, $\eta_p^2 = .51$, and ordinal trial position, $F(9,73) = 2.66$, $p < .010$, $\eta_p^2 = .25$, but no interaction of these variables, $F(36,46) = 1.15$, $p = .328$, $\eta_p^2 = .47$. Orthogonal contrasts revealed the typical irrelevant speech effect, that is, a reduction of serial recall in the distractor conditions relative to the quiet control conditions, $F(1,81) = 74.58$, $p < .001$, $\eta_p^2 = .48$. When the four distractor conditions were compared in an additional 2 × 2 MANOVA, a significant auditory deviant effect was observed, $F(1,81) = 16.19$, $p < .001$, $\eta_p^2 = .17$, that is, disruption was increased by auditory deviant sequences as compared with steady state sequences. There was no effect of taboo, $F(1,81) = 0.02$, $p = .964$, $\eta_p^2 < .01$, and no interaction between both variables, $F(1,81) = 0.63$, $p = .432$, $\eta_p^2 = .01$.

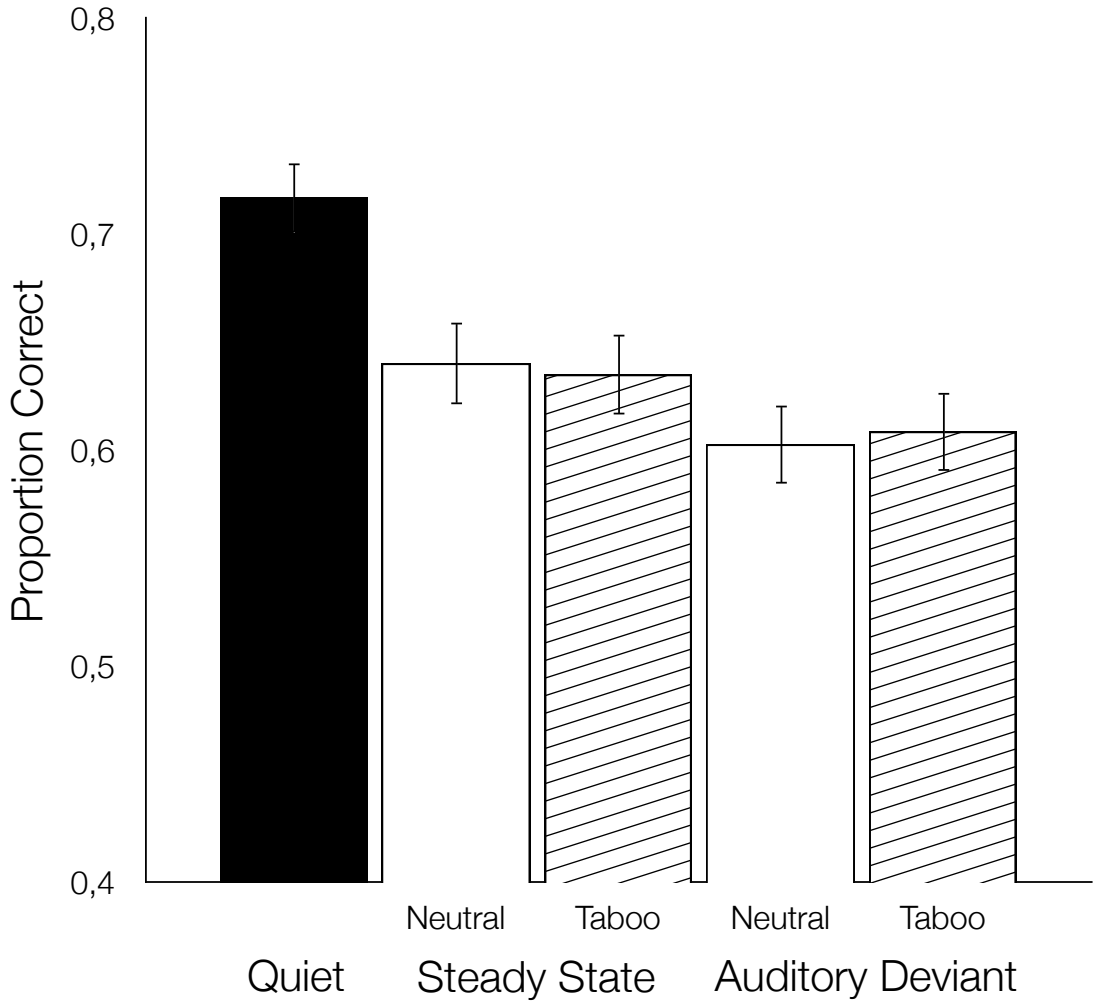

Figure 3: Recall performance as a function of sound condition (quiet, steady state neutral, steady state taboo, auditory deviant neutral, auditory deviant taboo) in Experiment 3. The error bars depict the standard errors of the means.

Discussion

When auditory deviant stimuli were used, an effect of semantic content was no longer observed. There was the typical auditory deviant effect (i.e., larger disruption by auditory deviant sequences compared to steady state sequences), however, auditory deviant taboo words were as disruptive as auditory deviant neutral words. This is inconsistent with the assumption that the taboo effect depends on attentional shifts to the auditory modality caused by other factors such as a violation of recent auditory regularities, which then result in the semantic processing of the auditory distractors (cf. Parmentier, 2008). If that were the case, the taboo effect should have been particularly pronounced for auditory deviant taboo stimuli, which are known to produce a large amount of attentional capture. On the contrary, we found that the taboo effect was abolished

when auditory deviant sequences were used. The results from Experiment 3 thus demonstrate that the attention-grabbing power of auditory deviant sequences due to the violation of recent auditory regularities cannot be further increased by the semantic content of the auditory distractors. By implication, this suggests that the taboo effect may not be conceptualized as the aftereffect of attention shifts to the auditory modality caused, for instance, by acoustic changes in the distractor material from one distractor word to another.

Experiment 4 served to replicate the findings of Experiment 3. To further increase the likelihood of finding a possible effect of semantic content, we made sure that the taboo words were as salient as possible. To this end, the repeated word in the auditory deviant sequences was always a neutral word. Thus, auditory deviant taboo words not only violated recent auditory regularities (i.e., a different word within a sequence of repeated words), but they also deviated in terms of their semantic content (i.e., a taboo word within a sequence of neutral words).

Experiment 4

Method

Participants

Eighty-four Heinrich Heine University students (64 women, *M* of age = 24) were paid for participating or received course credit. All participants were fluent German speakers and reported normal hearing and normal or corrected-to-normal vision.

Materials, Procedure, and Design

Experiment 4 was identical to Experiment 3, except for the auditory deviant taboo condition. In Experiment 3 four taboo words were presented, followed by a single presentation of a different taboo word, after which the original taboo word was presented another three times). In Experiment 4, only the deviant word was a taboo word. The repeated word was always a neutral word (e.g., "textbook, textbook, textbook, textbook, hardcore, textbook, textbook, textbook"). As in Experiments 1, 2, and 3 no two trials comprised the same word.

Results

Experiment 3 and 4 showed the exact same pattern of results. Figure 4 illustrates the serial recall performance as a function of sound condition (quiet, steady state neutral, steady state taboo, auditory deviant neutral, auditory deviant taboo). A 5×10-MANOVA yielded significant main effects of sound condition, $F(4,80) = 31.64$, $p < .001$, $\eta_p^2 = .61$, and ordinal trial position, $F(9,75) = 2.57$, $p < .012$, $\eta_p^2 = .24$, but no interaction of these variables, $F(36,48) = 0.79$, $p = .769$, $\eta_p^2 = .37$. There was a typical irrelevant speech effect, that is, the distractor conditions differed significantly from the quiet control condition, $F(1,83) = 89.46$, $p < .001$, $\eta_p^2 = .52$. Again, a 2 × 2 MANOVA revealed a significant auditory deviant effect, $F(1,83) = 85.68$, $p < .001$, $\eta_p^2 = .51$, but neither an effect of taboo, $F(1,83) = 0.70$, $p = .404$, $\eta_p^2 = .01$, nor an interaction of both variables, $F(1,83) = 0.01$, $p = .931$, $\eta_p^2 < .01$.

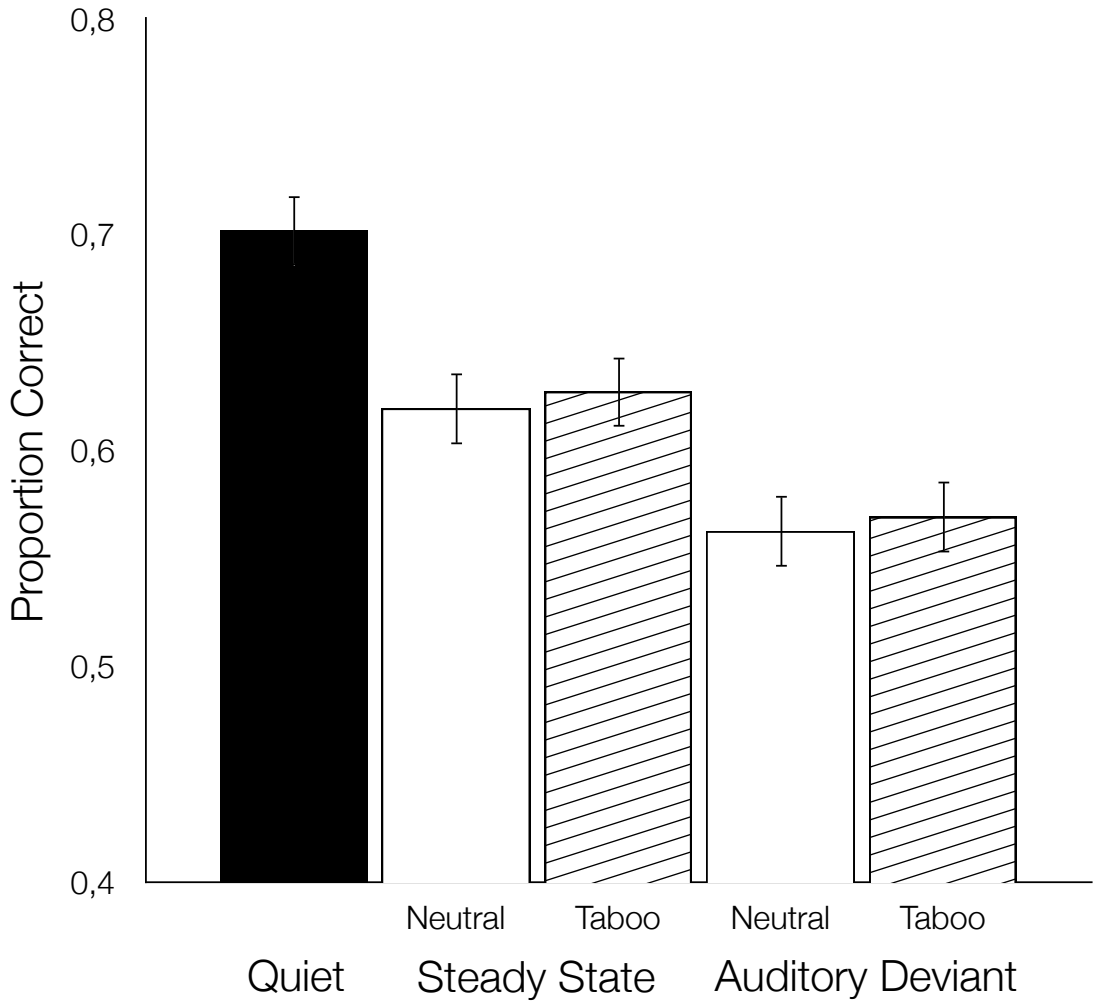

Figure 4: Recall performance as a function of sound condition (quiet, steady state neutral, steady state taboo, auditory deviant neutral, auditory deviant taboo) in Experiment 4. The error bars depict the standard errors of the means.

Discussion

The results of Experiment 4 directly replicated those of Experiment 3 in showing that no taboo effect could be observed when auditory deviant stimuli were used. Despite the fact that auditory deviant taboo words were more salient, they were as disruptive as auditory deviant neutral words. This suggests once again that the attention-grabbing power of auditory deviant stimuli cannot be further increased by their semantic content. We elaborate on the implications of these results in the General Discussion.

General Discussion

In the present series of experiments, we addressed a number of open empirical questions with regard to the effect of taboo words on serial recall performance. The overall pattern of results demonstrates that taboo words are more difficult to ignore than neutral words because they draw attention away from the primary task. Participants made significantly more errors in the changing state taboo condition (i.e., when eight different taboo words were presented) than in the changing state neutral condition (i.e., when eight different neutral words were presented). Interestingly, Experiments 1 and 2 revealed a significant interaction of semantic content and distractor condition. Serial recall performance did not differ between the steady state taboo condition (i.e., when the same taboo word was presented eight times) and the steady state neutral condition (i.e., when the same neutral word was presented eight times). This tells us that it is the word-specific meaning that produces the disruption rather than the mere fact that a taboo word is unexpected in the context of a psychological experiment at a university. If such an unspecific expectancy violation had been the cause of disruption, then the emotional response should have been attenuated regardless of whether the same taboo word was played repeatedly or whether a different taboo word was presented. A reduced disruption after repeated exposure to the same emotional stimulus has been observed in other paradigms as well. Participants took longer to name the color of new taboo words than that of taboo words which had been presented before (MacKay et al., 2004) and the repeated presentation of emotionally valent face stimuli led to habituation in the amygdala in form of an fMRI signal decrement (Wright et al., 2001).

The present data indicate that the semantic content of auditory distractors is processed even when focal attention is directed elsewhere. When a taboo word is detected, ongoing behavior is

interrupted in order to allow for an evaluation of the stimulus' relevance (e.g., its threat potential) for the individual (Bower, 1992; Cowan, 1999; MacKay et al., 2004; Mather & Sutherland, 2011). If the same stimulus is presented again, such an evaluation and the corresponding interrupt of ongoing cognitive processes are no longer necessary. If, however, a different stimulus is presented, then stimulus' importance must be evaluated anew, and ongoing processes are interrupted. In sum, the weight of evidence suggests that it is the word-specific evaluation and the cognitive interrupt that it triggers, which causes the taboo effect.

These results have direct implications for theories of memory and attention. With regard to the question of whether the task-irrelevant, to-be-ignored auditory distractors are processed semantically, or not, it was conceivable from the outset that semantic processing is unlikely to occur when task-relevant and task-irrelevant information are presented in different modalities, so that the distractors can be blocked off at an early stage of processing. Moreover, previous evidence of semantic auditory distraction effects was obtained with studies in which the to-be-remembered items were words as opposed to digits or consonants (Buchner & Erdfelder, 2005; Buchner et al., 2006; Buchner et al., 2004; but see Elliott & Briganti, 2012). These results could be interpreted to mean that the semantic processing of the auditory distractors should only have an effect on performance if the primary task relies on semantic processing as well (cf. Marsh et al., 2014). Semantic auditory distraction would then be the result of the systemic failure of the attentional system to constrain processing routines to the task-relevant information. It follows from this interpretation that the serial recall of digits should not be affected by the content of the auditory distractors. Inconsistent with this prediction, however, auditory taboo words had a pronounced effect on the serial recall of digits in the present series of experiments, even though this task does not rely on semantic processing.

We also tested a more specific hypothesis according to which the taboo effect may be conceptualized as the consequence of occasional attentional shifts to the auditory modality, which are either due to a failure to maintain the focus of attention on the task-relevant information or due to attentional capture by acoustic changes in the auditory material from one distractor word to another. As a result of such occasional attentional shifts, the semantic content of the auditory distractors may be processed, allowing for taboo words to be detected and to capture further resources away from the primary task. The present results however, do not lend support to this hy-

pothesis. First, this hypothesis would imply that individuals with low working memory capacity (i.e., individuals with a reduced ability to constrain attention to task-relevant information) should be more susceptible to the disruptive effect of taboo words on serial recall performance than individuals with high working memory capacity. This was disconfirmed by the results of Experiment 2, in which the magnitude of the taboo effect was unrelated to individual differences in working memory capacity. Second, the taboo effect disappeared when auditory deviant sequences were presented (Experiments 3 and 4). If the taboo effect was the consequence rather than the cause of attentional shifts to the auditory modality, there should be a pronounced taboo effect for auditory deviant stimuli, which are known to capture a large amount of attention away from the primary task. This was not the case. Thus, the present results suggest that the taboo effect cannot be conceptualized simply as an aftereffect of occasional attention shifts to the auditory modality.

Instead, the present data appear to be more in line with a functional view of auditory distraction according to which to-be-ignored, irrelevant speech is routinely monitored for its relevance to the individual. From a functional perspective, stimuli that are of importance for the individual (e.g., self-relevant or threatening information) should be detected in a to-be-ignored channel even when attention is directed elsewhere (cf. Cowan, 1999). This detection requires the semantic processing of auditory distractors to some extent, which may always consume a certain degree of attentional resources. When important stimuli are detected (e.g., self-relevant or threatening information), the cognitive and behavioral demands that they are associated with may cause the attentional system to allocate further processing resources which, depending on the outcome of the evaluation, may or may not result in a full attention switch towards the previously task-irrelevant event. Taboo words which are known to be emotionally arousing and signal a potential threat (Kensinger & Corkin, 2003; MacKay et al., 2004) should fall into this category, as should one's own name compared to that of a yoked-control partner (Röer et al., 2013). Of course, a mechanism that monitors the to-be-ignored modality for potentially important stimuli as it is proposed here would not be limited to speech sounds. A crying baby, a fire alarm, or a barking dog are examples of potentially important stimuli that should also be detected and lead to an attention switch. Nevertheless, it seems plausible that speech sounds (and sounds that resemble speech in their physical properties) play a special role. It has been shown, for instance, that not

only the content of irrelevant speech may have an effect on the distractors' potential to grab and hold attention, but also the urgency of intonation. Ljungberg, Parmentier, Hughes, Macken, and Jones (2012) were able to demonstrate that an urgently spoken distractor word had a greater disruptive effect on serial recall than a calmly spoken distractor word. For humans as social animals speech is the central medium of communication and semantic processing may be biologically prepared and almost unavoidable. If that were the case and the environment is indeed routinely monitored for potentially relevant stimuli, irrelevant speech should always be processed semantically to some extent, and this processing should occur independently of whether the primary task involves semantic processing, or not. In line with such a view, our results suggest that the amount of interference that an auditory distractor produces must not necessarily be indicative of the level to which it is processed: Although in several studies the semantic content of irrelevant speech has been shown not to interfere with ongoing performance (Buchner et al., 1996; Elliott & Briganti, 2012; Jones et al., 1990; Marsh et al., 2009), the taboo effect reported here demonstrates that the semantic content of irrelevant speech may be processed nonetheless and may capture attention away if it is of particular significance.

Despite the fact that, at first glance, the irrelevant speech effect seems to be provide evidence for a systemic failure of the attentional system (i.e., more errors are made as compared to a quiet control condition), we believe that it can also be viewed from a functional perspective. This would render the disruptability of working memory performance by auditory stimuli not a shortcoming of the attentional system, but rather it would show off its flexibility to detect and react to previously unattended information that may be of potential relevance for the individual. The present series of experiments provides preliminary evidence in favor of this interpretation.

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Author Notes

Jan Philipp Röer, Ulrike Körner, Axel Buchner, and Raoul Bell, Department of Experimental Psychology, Heinrich-Heine-Universität Düsseldorf, Germany. The research was supported by Grant RO 4972/1-1 from the Deutsche Forschungsgemeinschaft (German Research Foundation). Correspondence concerning this article should be addressed to Jan Philipp Röer, Institut für Experimentelle Psychologie, Heinrich-Heine-Universität, D-40225 Düsseldorf, Germany. Electronic mail may be sent to jan.roeer@hhu.de.