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The Process of Auditory Distraction: Disrupted Attention and Impaired Recall in a Simulated Lecture Environment

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Abstract

Literature on auditory distraction has generally focused on the effects of particular kinds of sounds on attention to target stimuli. In support of extensive previous findings that have demonstrated the special role of language as an auditory distractor, we found that a concurrent speech stream impaired recall of a short lecture, especially for verbatim language. But impaired recall effects were also found with a variety of non-linguistic noises, suggesting that neither type of noise nor amplitude and duration of noise are adequate predictors of distraction. Rather, distraction occurred when it was difficult for a listener to process sounds and assemble coherent, differentiable streams of input, one task-salient and attended, and the other task-irrelevant and inhibited. In three experiments, the effects of auditory distractors during a short spoken lecture were tested. Participants recalled details of the lecture and also reported their opinions of the sound quality. Our findings suggest that distractors that are difficult to designate as either task-related or environment-related (and therefore irrelevant) draw cognitive processing resources away from a target speech stream during a listening task, impairing recall.

Keywords: attention; auditory processing; distraction; language; laughter

The Process of Auditory Distraction: Disrupted Attention and Impaired Recall in a Simulated Lecture Environment

Sometimes extraneous noise impedes attention and memory, and sometimes it does not. The distraction is not adequately accounted for in terms of the auditory or semantic characteristics of the noise. An interference-by-process account of auditory distraction can reconcile diverse findings in this area (e.g., Jones, 1999). This account describes auditory distraction not as a function of the content of noise as earlier research has claimed (for a review, see Marsh, Hughes, & Jones, 2009), but rather as a function of the work entailed at resolving auditory input into structurally or semantically coherent streams that are then either inhibited or attended to, depending on current goals. Our study supports and expands the findings in this area. We test recall of a much longer speech stimulus than has been used in prior tests of interference-by-process, and we use a range of naturalistic noise conditions to test the robustness of this account in more realistic contexts.

In three experiments, we tested the hypothesis that difficulty with auditory streaming causes auditory distraction. We propose that an account of auditory distraction during a listening task with a speech stimulus must allow for at least two processing tasks: (1) the processing necessary for organization and comprehension of a target speech stream and (2) the processing necessary for the assembly and maintenance of a mental representation of the environment within which a listener is operating.

How We Process Sound

Sound, unlike vision, is processed obligatorily and continually. We can close our eyes, turn our heads or orient our eyes to control what we see, but our ears are always open to auditory input. Our hearing system needs to be able to attend to a given task while remaining open to new information in the environment so that we can shift focus if and when it is necessary. We process all of this auditory input not unlike we process visual input; we group sounds into meaningful objects and events. Grouping principles like the Gestalt principles that govern visual perception are used for the processing of auditory input and make an overwhelming amount of sensory input manageable and usable (e.g., Treisman & Schmidt, 1982; Deutch, 1972; Julesz & Hirsch, 1972).

We group sounds for meaning on at least two levels. We use the physical features of sounds such as fundamental frequencies, locations, harmonics, sequence, chronological spacing, and seriation to assemble mental entities from sound, as with specific people's voices or particular musical instruments. We also use learned patterns or schemas to make sense of sound that should have familiar or recognizable elements and structures, as in speech or a piece of music. This cognitive processing of the auditory scene into streams allows us to construct a coherent mental representation of our environment and its constituent elements. Then, knowing what is present around us but irrelevant to a given goal, we can inhibit some streams of noise and attend only to stimuli that relate to a goal (Bregman, 1995; Jones, Hughes, Marsh, & Macken, 2008).

What causes auditory distraction?

Many researchers have demonstrated that a noise's acoustic characteristics, semantic characteristics, and task salience can predict whether the noise will distract. The criteria used by a listener to make a selection from auditory input included amplitude, frequency range and variation, rhythm, location of sound origin in space, and particular salience to a listener (such as his or her name in a rejected, unattended ear in dichotic presentation, or comprehensible speech).

There is also ample evidence for an auditory *startle effect,* with loud and sudden noises producing emotional and physiological arousal, distracting attention, and impairing performance on concurrent tasks (Woodhead, 1958; Vlasak, 1969). This impairment is temporary, and performance on cognitive or recall tasks recovers within seconds (Thackeray & Touchstone, 1970). The startle effect has a clear neuronal basis, and appears to be homogenous in mammal species, functioning as an adaptive protection against a sudden threat (Koch, 1999). But much distraction occurs when irrelevant noise is at levels equal to or lower than normal speech, or is continuous. It is the mechanism of this distraction that we tested.

Early work suggested that there was a filter mechanism that (1) selected the noises we wanted to hear based on acoustic or semantic characteristics and (2) blocked other noises. But, contrary to such an account of selective attention, there is evidence that we have awareness of a wide variety of features of input from unattended channels; if we didn't, shifts of attention and distraction would be rare or impossible (for a review, see Holender, 1986). Selective attention theories that depend on the blocking or attenuating of specific distracting noises during selective listening do not adequately explain the data in this area.

Interference-by-Content vs. Interference-by-Process

Below we present a few examples of studies of auditory distraction that examine the effects of three different kinds of noise: aperiodic noise, speech with and without semantic content, and task salient noise. The findings of these studies are considered first in the context of the *interference-by-content* hypothesis, which proposes that it is the content of noise either by itself or in conjunction with a given task that causes distraction (e.g., Beaman, 2004; Neely & LeCompte, 1999). The findings are then considered in view of the *interference-by-process* hypothesis, which proposes that distraction results not from specific sensory input per se, but from difficulty in cognitively processing and separating information into discrete streams for attention and inhibition (Hughes & Jones, 2005; Jones & Tremblay, 2000; Neumann, 1996).

A number of studies looked at the effects of various noises on the quality of work on a range of tasks. These studies highlighted the effects of irregularity, volume, and language in noise distractors. Complex psychomotor activity in an aircraft simulator was impaired by white noise, with the greatest effects obtained by aperiodic bursts at high volume, the least impairment with continuous noise at low volume, and moderate impairment with periodic bursts at moderate volume (Eschenbrenner, 1971). Intermittent bursts of typewriter noise reduced performance on the detection of grammatical errors during a proofreading task, but had no effect on detection of spelling errors or recall of the content of the passage (Weinstein, 1974). The sound of other children babbling impaired the performance of 8-9 year old children on verbal and math proficiency tests, and was more detrimental overall than both no noise and the sound of babbling with other school-related environmental noise (Dockrell & Shield, 2006). Office noise with speech was shown to impair performance more than office noise without speech on both semantic prose comprehension and mathematics tasks (Banbury & Berry, 1998). And short-term serial memory for a series of letters was distrupted by one or two voices speaking far more than the sound of groups of six or more, and these effects obtain even when the distracting voices were speaking a language participants did not understand (Jones & Macken, 1995).

According to the interference-by-content hypothesis, distraction is caused by the type of noise (for example, linguistic noise or aperiodic noise) or the noise in combination with the task (for example, linguistic distractors' impairing work on language-based tasks). But this account cannot fully explain these data or offer consistent mechanisms for the distraction. For example, why would the irregularity of white noise be the operative factor in psychomotor impairment? Eschenbrenner proposed that it causes increased "stimulation" which competed with the target task, but the character and mechanism of this competition was not addressed (1971, p. 62). It is also unclear why intermittent typewriter noise impaired work on one kind of reading task, grammar error detection, but not spelling error detection or content recall, arguably of similar difficulty (Weinstein, 1974).

Further, from an interference-by-content account it is unclear why verbal background noise resulted in less impairment when paired with other background noise and why the sound of fewer voices was more distracting than the sound of many voices (Dockrell & Shield, 2006; Banburry and Berry, 1998; Jones & Macken, 1995; note that Jones & Macken do not support the interference-by-content hypothesis). If language, as semantic input, impairs a task that requires semantic processing, it should have distracted equally whether it occurred by itself or paired with other noise, as long as it was equally discernable as language in both conditions. More obviously at odds with an interference-by-content hypothesis, why would a foreign language cause as much distraction as a native language, as Jones and Macken (1995) found? A semantic interference account is incomplete, because a foreign language should interfere less semantically. In short, the hypothesis that acoustic distraction results from the interference of particular noises in particular contexts does not adequately explain acoustic distraction.

According to the interference-by-process hypothesis, distraction is caused by the increased cognitive load entailed when it is difficult to process and differentiate multiple streams of information in the auditory environment for the purpose of inhibiting one or more of them and attending to another (Jones, 1999; Jones, Miles & Page, 1990; Macken, Phelps & Jones, 2009). Acoustic distraction is more complex than the phonology, rhythm, or even semantics of the linguistic sound, or indeed any sound.

According to interference-by-process, irregular noise should be more difficult to group into a coherent, irrelevant stream and therefore more difficult to inhibit, as observed in the study of increased difficulty with psychomotor tasks while hearing irregular white noise (Echenbrenner, 1971), and as observed with the intermittent typewriter noise (Weinstein, 1974). In the same way, distracting noise that in combination with other noise becomes less difficult to designate as target or environment should distract less, as observed in the studies where verbal background noise paired with environmental noises caused less distraction (Dockrell & Shield, 2006; cf. Banbury & Berry, 1998), and in the study where larger groups of voices distracted less than one or two voices (Jones & Macken, 1995). Said another way, the verbal background noise was more easily grouped into a single background noise stream, allowing it to be inhibited with less effort.

Particular tasks being differentially affected by distractors is also addressed by interference-by-process. Tasks that require more structure-building, such as serial recall, should be disrupted more by problems organizing and binding input than processes that require less structure-building, such as recall of a single item from a series. For example, in a serial recall task, input and rehearsal of items for memory involve more structure-building than retrieval of the items, so there should be more disruption when noise is present during input and rehearsal stages than if it is present during retrieval. An alternative prediction would be that distraction affects each stage of a memory task similarly. Actually, distractions interfered most during input and rehearsal (Miles, Jones & Madden, 1991). As another example, an irregular varying tone distractor disrupted recall of the order of items to be remembered, but not the recall of any constituent part of the series (Jones & Macken, 1993). In short, target tasks that require attention to structure, such as Weinstein's grammar-based task, may be particularly vulnerable to distraction of this kind. The processing resources being overtaxed by the effort at structuring and binding distracting stimuli for attention or inhibition may be just those that would be needed most for a grammar-error detection task, but less for a content recall or spelling-error detection task.

Finally, according to interference-by-process, speech's semantic content should have no special status as a distractor, with distraction resulting solely from the extent to which noises can be grouped into a coherent, irrelevant stream. Accordingly, intelligible and unintelligible irrelevant speech and speech-like sounds distracted similarly during serial memory tasks (distractors were English, reversed English, and Welsh, with targets in English and with monolingual English-speaking participants; Jones, Miles & Page, 1990; see also Jones & Macken, 1995, regarding comprehensible versus incomprehensible language). It is still possible that speech and speech-like sounds have special status as distractors, but if it is not because of semantic content or phonetic similarity, this status is difficult to characterize. The other possibility, following interference-by-process, is that speech and speech-like sounds cause a specific kind of structure building where non-speech-like sounds do not. In support of the structure-building conclusion, semantics plays a role only if both task and distractor require organization of semantic entities during encoding and rehearsal (e.g. Marsh, Hughes & Jones 2009).

Expectations also bear on how organization of stimuli is done. Researchers have documented that previous knowledge and preconceptions about sounds and environments can affect processing. Vachon, Hughes, and Jones (2012) showed that changing the voice delivering irrelevant speech unexpectedly from male to female during input stages of a visual serial recall task impaired performance. However, the first encountering of a voice (the point at which the distractor was novel) did not impair recall. Vachon et al. (2012) argue that this is because listeners had not built up an expectation to be violated. Further, participant recall did recover when distractors began to alternate in predictable patterns, male to female. These results suggest that violated expectation, not novelty, is why irrelevant stimuli distract.

In summary, experiments using target stimuli such as series of letters and numbers and auditory distractors such as tones and engineered speech streams have demonstrated that organizing information is an important factor in encoding and recall. Can these findings bear on larger, situational constructs where listener expectations about what should occur and what should not are active? And can the interference-by-process account help make predictions about distraction when sounds need to be sorted into attention-meriting *speaker sounds* and attention-inhibiting *environment sounds*? In order to test this, we designed a study in which both target speech and distractors are longer, more complex, and intended to simulate a more realistic learning environment.

Current Experiments

In three experiments, we tested an account of the mechanism of auditory distraction as a result of difficulty separating task input streams from distractor input streams. Our research questions, hypotheses, and mechanisms for expected effects are summarized in Table 1.

Each of the three hypotheses in Table 1 predicts that it is not the content of a distractor that distracts, but it is rather the process employed to group and separate sound into what should be attended to and what should be inhibited when this work at separation becomes difficult. If organizing sound into coherent streams is related to the assembly of a mental structure, then difficulty doing so should particularly affect the processing and memory for surface structures in the target speech. That is, there should be overall impairment on recall because memory requires organization and encoding of discrete items into a mental structure that can later be recalled, but there should be greater impairment for pieces of verbatim language because organization and encoding of verbatim information is more difficult than organization and encoding of gist information.

Experiment 1: What Distracts from a Lecture, and Why?

In Experiment 1, the effects of auditory distraction on recall of a short lecture were compared across five distracting noise conditions and one no-noise control condition. The distracting noise conditions were (1) overlaid lecture, (2) added audience laughter, (3) construction noises, (4) audience murmuring, and (5) audience shifting in their seats.

Of these six conditions, only the overlaid lecture and added laughter conditions contained auditory streams that are normally produced in finely timed and coordinated structures as part of a linguistic interaction (Provine, 1993; Partington, 2006; Jefferson, Sacks & Schegloff, 1977). These two conditions constituted auditory input that was similar to the target speech stream (finely timed and coordinated structures) but at the same time requiring separation from the target speech stream and inhibition. Thus, the interference-by-process hypothesis predicts that speech and artificially added laughter result in impaired recall of the lecture. In addition, because organization and encoding of verbatim information was expected to require more structure-building than organization and encoding of gist information, verbatim recall should be worse than gist recall.

The remaining three distraction conditions tested the effects of naturalistic environmental noise on attention. In the audience murmuring, audience shifting, and construction noise conditions, the noise was calibrated to be virtually identical to the artificial laughter condition in amplitude and duration. According to the interference-by-process hypothesis, if these noises are perceived as part of the lecture environment, they should be easily streamed as non-target and inhibited, producing little distraction. There should be no difference between verbatim recall and gist recall.

The interference-by-content hypothesis makes different predictions. First, if there is an affective, positive effect of the sound of laughter and if positive affect broadens attention, performance should be better in the added laughter condition, possibly even better than the quiet control (Bachorowski & Owren, 2003; Rowe, Hirsh & Anderson, 2007; Olivers & Nieuwenhuis, 2006). If there is a negative affective response to any non-task noise that is irregular in amplitude and duration, then the artificial laughter, construction noise, audience murmuring, and audience shifting conditions should all distract, and the control and the overlaid lecture conditions should not (Broadbent, 1958; Campbell, 2005). If language distracts because of its semantic and phonetic properties, especially considering that the task is listening to and encoding language, then only the overlaid lecture condition should distract (Salamé & Baddeley, 1982). If any noise with semantic meaning distracts, laughter, murmuring, shifting, and the overlaid lecture should all distract because they could be interpreted as informative about the attitude and behavior of the audience (Smith, 1985).

Method

Participants. Two hundred and sixteen University of California students participated in exchange for course credit.

Materials. A 5-minute lecture from the TED online lecture archive was selected. The lecture presented statistical analyses of reviews of prior TED talks with accompanying lively laughter and applause from the audience. At our request, the TED speaker read a transcript of the original lecture in a quiet setting using high-quality recording equipment. This yielded the control condition with no audiences or other noise, and a consistent stimulus in regards to content of the target semantic material.

Five test conditions were created from this control audio lecture by adding and overlaying sounds. As mentioned above, the amplitude of four of the total six conditions (excluding the overlaid lecture and the control conditions) was manipulated to emulate the patterns observed with the live audience noise from the original, growing louder or softer at similar points. The difference in low noise levels and high noise levels in the four non-comprehensible speech conditions was an average of 22 decibels. The five test conditions were: (1) added audience laughter, (2) an economics lecture, used by permission, overlaid at a steady 10 dB lower than the target speech stream, (3) construction noises, (4) audience murmuring, and (5) audience shifting. Non-lecture sounds were obtained from Audiencesounds.com and from an audio file with recorded construction noise available on YouTube (Construction Sounds, n.d.). The overlaid lecture was obtained from the *Economist* magazine web audio archive ("Mexican Cinemas in India," 2011).

A 28-item multiple choice quiz was created to test recall of the lecture. The quiz included 12 questions testing verbatim recall and 16 questions testing gist recall. The gist and verbatim recall questions asked about different, not overlapping, content from the lecture.

Manipulation Check. To assemble some qualitative data on how the sound stimuli were perceived by participants, a manipulation check of the six conditions was conducted, with groups of between 8 and 13 participants per condition. Participants in the manipulation check heard a two-minute clip of one of the six audio stimuli for Experiment 1: either the control condition or one of the five constructed stimuli. Then they provided a single answer to the following open-ended questions, asked together: "What was the picture in your head when you were listening to the talk? What did you imagine was going on in the room with the speaker?"

In the control condition, we noted that 8 out of 13 listeners imagined that the speaker was speaking to a silent audience. In the added laughter condition, 2 out of 9 listeners mentioned that the laughter sounded artificial. In the overlaid lecture condition, 8 out of 9 listeners described a concurrent human voice, such as another lecture or a news report. The 9th listener described the overlaid lecture as “a tiny fuzz of inspirational sounds.” In the construction noise condition, 7 out of 8 listeners mentioned construction noise. The 9th listener described a speaker and a silent audience, with no mention of other noise. In the murmuring condition, 10 out of 11 listeners described the speaker as being amidst crowds engaged in various activities, with 8 of these 10 mentioning voices. Some comments follow: “people moving around, discussing things, walking in or out of the room,” “I imagine that no one was listening and that people were turning their attention to other things,” “I believed I was in a lecture hall in college talking to a professor as students filed out the back of the class while making noises,” “I imagined the speaker was on a stage by himself in a cafe or restaurant, or some other room full of people that isn’t an auditorium. I imagined no one was listening to him.” The 11th listener described a lone speaker, with no mention of other noise. In the shifting condition, 9 out of 10 people mentioned audience movement. The 10th person mentioned audience talking, although there was no talking in the overlaid sounds. One of the 9 movement-mentioners also mentioned talking.

In summary, listeners were able to produce a variety of mental images of the scene from the auditory input in each condition. The overlaid lecture and murmuring conditions were heard as linguistic noise. The overlaid lecture was described with minimal environmental detail, as a monologue, and the murmuring was heard as environmental noise produced by a large group of distracted audience members talking amongst themselves. The construction noise and shifting conditions were heard as nonlinguistic noise occurring in the background of the talk. The construction noise was interpreted as the sound of machines and the shifting as sounds produced by a group of humans.

Procedure. Participants were told when they arrived for the study that they would hear a short lecture and that after the lecture they would take a short "quiz and questionnaire." Participants were instructed to listen "as they would to any lecture" and answer the questions that followed "as best as they can." They were not given a time limit. Participants then listened to one of the six versions of the TED talk on a Macintosh computer. When participants were finished listening to the audio stimulus, they were immediately directed via on-screen instructions to the web-based questionnaire, and proceeded to answer the recall questions that followed there.

Results

Overall recall varied by condition, $F(5, 210) = 2.61$, $p = .026$. Effects were driven by low scores on verbatim recall, which varied by condition, $F(5, 210) = 5.36$, $p < .001$, where gist recall did not, $F(5, 210) = .93$, $p = .46$ (see Table 2). Linear contrasts supported the interference-by-process hypothesis: (1) participant scores on overall recall did not differ between the laughter and overlaid lecture conditions, $t(210) = .95$, $p = .34$, and (2) participants scores on overall recall were worse in the laughter and overlaid lecture conditions compared to the other conditions, $t(210) = 3.21$, $p = .002$.

Discussion

Across the six conditions, only the overlaid lecture and artificial laughter conditions impaired recall compared to the control condition. Because three of the five added noise conditions did not negatively impact performance, results cannot be explained by an interference-by-content hypothesis where all added noises sound odd and distract attention.

In addition, laughter did not produce a positive-affect effect of improved recall. The presence of laughter has been touted as improving teaching effectiveness (Stambor, 2006). These results suggest that simplistic views of the positive benefits of laughter on learning are unlikely to tell the whole story.

Other versions of the interference-as-content hypothesis were also not supported. If duration and amplitude were important, then the laughter, construction noise, murmuring, and shifting conditions should have produced similar distraction effects: They did not. If speech is a special distractor especially when the task is speech-related, then only the overlaid lecture should have distracted. If the semantic content of noise was essential to distraction, then the noises with discernable linguistic content (overlaid lecture) and the noises with potential to indicate audience attitude (laughter, murmuring, shifting) all should have distracted, but only two did.

The impairment in both the overlaid lecture and the laughter conditions was driven by reduced ability to recall verbatim features of the lecture. This suggests, consistent with the interference-by-process hypothesis, that recall of surface structures of language may be particularly vulnerable to the increased processing load during encoding: The load is incurred as participants draw on limited cognitive resources to organize and inhibit non-task noise. That is, processing the irrelevant concurrent speech stream and the equally irrelevant sound of artificial laughter were similar enough to the target task of processing, organizing, and encoding language that distraction occurred.

One alternative explanation for the results is that an intelligible human voice is a highly salient sound, attracting listener attention more than other environmental noises, allowing less attention for the target lecture. This explanation is a version of the interference-by-content hypothesis, but instead of merely noise with linguistic implications being salient, this *human-voice* sub-hypothesis proposes that the human voice has special qualities that draw attention.

In conjunction with the human-voice sub-hypothesis, it is also possible that the read re-recording of the TED talk may have been harder to follow because it was produced without live audience feedback (cf. Fox Tree, 1999), causing it to sound different, possibly less engaging, than a talk produced with feedback from an audience -- even if only the speaker's voice were taken into consideration. This difference may have exacerbated the attentional draw of the two conditions with potentially intelligible, potentially highly salient human voice distractors.

In Experiment 2 we tested the human-voice sub-hypothesis of the interference-by-content hypothesis by comparing recall across three human voice conditions: original audience noises, original plus added audience laughter, and original plus a set of unusual added human- and non-human generated sounds. The content of the distractors in the original condition and the added-laughter condition was the same. The added laughter consisted of laughter found in the original version that was copied and overlaid onto the original version at locations where it did not originally occur. While the human-voice sub-hypothesis predicts no differences across these conditions, the interference-by-process hypothesis does predict differences.

In Experiment 2 we also tested the generalizability of the interference-by-process hypothesis by testing recall of the original, live audience TED talk instead of the read, re-recorded version of the same TED talk used in Experiment 1.

In contrast to the interference-by-content hypothesis, the interference-by-process hypothesis predicts that the two added noise conditions will distract more than the original condition. Noises will distract not because of their content, which is identical in two of the conditions, but because of participants' ease at constructing an overall mental representation of the listening environment. With ease of construction of a mental representation of the listening environment comes ease at designating criteria for and therefore attending to relevant information, and likewise inhibiting irrelevant information. Thus, more easily-constructed mental representations should result in better recall than more difficultly-constructed mental representations.

Experiment 2: Is Incongruity what Distracts?

In Experiment 2 we tested whether more and less incongruous distractors, amounting to settings that met listener expectations more and less well, predicted distraction. We compared distraction effects of (1) noise that was naturally occurring as part of an ongoing speaker-audience interaction with (2) identical noise that was copied and added to the original where it did not originally occur, and with (3) unusual audience noise that was added to the original.

According to the interference-by-process hypothesis, both the additional-newly-placed audience noises and the unusual audience noises should cause listeners to have difficulty creating a coherent mental picture of the environment, and therefore difficulty inhibiting the distractions in order to pay attention to the target lecture.

According to the interference-by-content hypothesis, there are at least two possible outcomes. First, if it is the character of acoustic noise that distracts, including the human-voice sub-hypothesis, then all three conditions should result in impaired recall because non-target noise—audience laughter, applause, and cheering—is present in all of them. Second, with or without impairment from the identical audience noise across the three conditions, impairment may occur more with the unusual audience noises because they may sound jarring and annoying.

We complemented the quantitative results of recall across these three conditions with qualitative data on participants' reports of the mental picture they were able to make of the listening environment in each condition. According to the interference-by-process hypothesis, the more realistic participants find the audio and the more coherent the mental picture participants described, the less distraction they will experience.

Method

Participants. One hundred and seventeen University of California students participated in exchange for course credit.

Materials. Three conditions were created using the original 5-minute lecture from the TED online lecture archive. In the original audio from the TED talk, which was recorded in front of a live audience, there was considerable naturally occurring audience applause, cheering, and laughter. This was the first condition. Two additional conditions were created using this audio. In the *heightened laughter* condition, the audience's spontaneously generated laughter was copied and overlaid onto portions of the original talk where the speaker did not pause, or where there was no intelligible end-of-utterance for them to react to. Apart from copying it and adding it in these places, no other changes were made to this laughter. In the *unusual noise* condition, the same original audio containing the real audience response noise had several unlikely sounds added to it. These sounds were 1-1.5 second audience noises spaced 15-30 seconds apart: a man groaning as if in pain, a man shouting as if in fear, two different sounds of crumpling paper, a man coughing, a woman coughing, a man clearing his throat vigorously, a woman sneezing, and a small group of men booing. The amplitude of these sounds varied from the mean amplitude of the speaker by no more than 15 dB, the biggest difference being the case of the group of men booing. The sounds were obtained from Audiencenoise.com.

Procedure. As in Experiment 1, participants listened to one of the versions of the TED talk and then completed the quiz. In order to get subjective perceptions on how easy it was to construct a mental picture, after the quiz participants answered two additional questions. They used a feeling thermometer tool, where a mouse is used to slide an indicator across a bar on the computer screen to give a rating 0-100 (0 = not realistic at all, 100 = very realistic) in response to the question "How realistic do you think this background noise sounded?" Last, they answered the open-ended questions that were used in the manipulation check for Experiment 1: "What was the picture in your head when you were listening to the talk? What did you imagine was going on in the room with the speaker?" We collected these ratings and comments for some complementary qualitative confirmation that participants were or were not able to create coherent mental representations of the talk and the surroundings as they were listening across the three conditions.

Results

Qualitative results. There were considerable differences in how participants responded to noise across conditions. Mean ratings on how realistic the background audio was were much lower in the heightened laughter condition and unusual noise condition than they were in the original audience noise condition, with broad standard deviations for each group. On a scale of 0-100, natural laughter received a mean rating of 69 (SD 28), heightened laughter, 28 (SD 28), and unusual noise, 18 (SD 22).

Content analysis on the open-ended questions revealed more detail about how the different noise conditions were perceived. In the original audience noise condition, we were only able to use 9 out of the 30 responses on the open-ended questions because of problems with the web-based survey tool. Eight out of the 9 listeners mentioned that the speaker was speaking to an appreciative audience. All 9 listeners reported a mental image that included a man, speaking on a stage, with the sound of clapping.

In the heightened laughter condition, all 27 listeners noted an audience, and most mentioned an appreciative audience. But participants who heard the heightened laughter were less consistent both within their own descriptions and between descriptions. Five participants described the talk as a comedy routine, and one as a “sitcom.” Eight other listeners made explicit reference to being unable to create a coherent picture of the scene, or noted more than one mental image at the same time, as in the following: “I imagined a comedic routine because of all of the laughter. But then I realized the laughter did not always correlate to what the man was saying;” “The audience was laughing because of something else that was going on beside the talk (something visually entertaining);” “I imagined him on the stage, where had [sic] a large audience but I realized that the audience seemed to be fake. He was probably with no audience, and he was in a small room that could record his talk as I assumed;" "The man was talking in a lecture hall or classroom with not a lot of people and some people but the noise of the people were implanted and fake;" "I was not picturing anything when I was listening to the talk. I was imagining people laughing with the speaker's speeches."

In the unusual noise condition, reporting was even more inconsistent, and lacked specific detail about the listening environment. Only 14 of 27 listeners mentioned an audience at all, though the same naturally occurring audience response noise was there. All listeners described a speaker giving a formal talk in a staged setting. Two listeners mentioned that the laughter sounded "fake," and two others said that the stimulus seemed to have been engineered in a sound studio. Only one listener specifically noted the added noises: "I imagined that someone listening to the TED talk re-recorded it making random noises to see how it affected our memory of it. And/or the person filming the lecture did that, but it was too random. If it was only coughing, I might have thought it was not on purpose."

In summary, the original audience noise condition was more realistic to listeners than the other two conditions -- as it should have been, because it was the original production presented before a live audience. It produced consistent descriptions both within one response and across listeners. The heightened laughter condition was heard as unrealistic, and it was described variously as a lecture, a comedy routine, a "sitcom" with a studio audience, and even some combination of these within one response. While the added noises in the unusual noise condition were not explicitly referred to by most listeners in open-ended comments, this condition received the lowest realism ratings of the three groups, and far fewer participants mentioned an audience at all (although there were normal audience noises present, just as there were in all three conditions in this experiment). In the unusual noise condition, reported mental images became indistinct, lacking the detail of the other two conditions. When an audience was mentioned in the unusual noise condition, it was often thought of as fake, although the general audience noise was in fact original. In sum, participants were able to report mental images in almost all cases, but their ability to put the images together into a single coherent auditory scene differed across conditions.

Quantitative results. Recall varied by condition, $F(2, 116) = 6.86$, $p = .002$ (see Table 4), as did both gist and verbatim recall, $F(5, 116) = 5.07$, $p = .008$, for gist recall, and $F(5, 116) = 4.20$, $p = .017$, for verbatim recall. Linear contrasts supported the interference-by-process hypothesis: (1) participants' scores on overall recall were worse in the heightened laughter condition and the unusual noise condition compared to the original audio condition $t(95) = 3.62$, $p < .001$, and (2) participant scores on overall recall did not differ between the heightened laughter condition and the unusual noise conditions, $t(48) = -.44$, $p = .662$.

Discussion

In Experiment 2 we found that naturally occurring noise that was perceived as part of an interaction with a speaker did not distract, but the same noise heard in places where laughter was not originally produced did distract, and was perceived as unrealistic by participants. Incongruous noises spliced into the original audio were perceived as the most unrealistic and produced a similar distraction effect to heightened laughter. Both gist and verbatim recall were impaired in the conditions where the background noise was rated as extremely unrealistic. This may be because the amount of structural processing work required to encode them was greater, resulting in greater interference with the organizational and encoding processes necessary to commit to memory not only the surface structure, usually fragile in memory, but also the propositional content (Sachs, 1967). That is, greater sense-making work in Experiment 2 led to problems with both gist and verbatim recall in comparison to Experiment 1, where only verbatim recall was impacted.

These data support the interference-by-process hypothesis. Recall decrements followed difficulty in constructing a mental representation of the listening environment. According to the interference-by-content hypothesis, all three conditions should have resulted in similarly impaired recall because non-target noise, audience laughter, applause, and cheering were present in all of them. Furthermore, it was not the salience of a human voice that drove listeners to focus attention on the irrelevant laughter and overlaid lecture in Experiment 1: salient human voices occurring in the original TED talk recording with no added noises did not result in decreased performance as compared with the no-added-noise control condition from Experiment 1, $t(94) = .35$, $p = .73$.

A remaining prediction of the interference-by-process hypothesis is that recall decrements should manifest uniformly over the course of comprehending a target speech stream. According to the interference-by-content hypothesis, recall decrements may be more serious at moments closely linked to when a distractor was heard. This *jarring-noises* sub-hypothesis of the interference-by-content hypothesis could even be used to explain the results of Experiment 1 and 2. Jarring noises could be seen as a minor startle effect. Noises may not need to be loud or sudden to create a pull on attention.

According to the jarring-noises sub-hypothesis, sounds that are out-of-place, odd, or jarring will cause a sense of surprise when the sounds are heard, causing a momentary shift of attention at the site of the noise, which can be thought of as either a minor startle effect or as a different effect without the neuronal basis of the startle effect. If similar to the startle effect, the jarring noises would result in poor recall of information presented after that noise with performance recovering quickly after (Thackeray & Touchstone, 1970). Cumulatively, this jarring effect (whether startle-related or not) could produce the overall impairment observed in the means analyses of Experiment 1 and 2.

We tested the jarring-noises sub-hypothesis of the interference-by-content hypothesis by inserting incongruous noises at several points in the lecture and testing how well information near these noises was recalled. The interference-by-content hypothesis predicts that only recall of lecture material near the incongruous stimuli will be impaired. The interference-by-process hypothesis, in contrast, predicts that impairment will occur continuously, with no surprise-related shifts of attention when distracting sounds are heard.

Experiment 3: Is Distraction Momentary or Continuous?

According to the interference-by-process hypothesis, as long as distractors are neither obviously part of the target speech nor obviously part of the environment, they should be difficult to bind to either. This should result in ongoing, continuous distraction from the target lecture.

In contrast, the jarring-noises sub-hypothesis of the interference-by-content hypothesis predicts greater impairment for lecture concepts coincident with the distracting noises, reflecting momentary or sound-specific draws on processing resources.

First, if a sudden break from the continuous sound of the speaker's presentation produces a momentary shift in attention to that sound, recall for information immediately following or even near to each of these noises should be impaired, excluding the silent control. If sheer difference in acoustic quality from the sound of the speaker's voice distracts, then we would expect the sinusoidal tone and the crumpling paper to produce the largest momentary effect. Alternatively, if the special character of speech or laughter is the key factor in distraction, then only information following or near to laughter or whispering should distract, and the distraction should occur at the sites of these noises only.

Four short incongruous noises and one silent pause as control were inserted into the short lecture used in Experiment 1. The noises were laughter, whispering, crumpling paper, and a sinusoidal tone. As in Experiment 2, the noises differed in amplitude from the mean of the speaker by no more than 15 dB, the biggest difference in this case being the crumpling paper. Recall was tested as in Experiments 1 and 2. The sounds occurred in brief bursts at random points in the delivery of the lecture.

Method

Participants. Fifty-four University of California students participated in exchange for course credit.

Materials. The control condition from Experiment 1, the 5-minute lecture read by the TED presenter in a quiet setting, was used as the target speech for Experiment 3. Five stimuli were created from this 5-minute lecture, counterbalancing the effects of five inserted noises, 1-1.5 seconds each. Each of the 5 counterbalanced conditions presented the same five noise conditions in the same locations, with only the order changing—laughter, whispering, crumpling paper, a sinusoidal tone, and silence. The changes in the order allowed for comparisons of recall rates at particular locations in the lecture that were independent of the difficulty of the questions.

Procedure. Participants listened to one of the five versions of the TED talk and then completed the recall quiz, as in Experiment 1.

Results

Both a means analysis and a direct logistic regression were used, to assess both overall recall and any local effects of the inserted noises.

A 2-samples *t*-test was conducted to compare overall recall in Experiment 3, where incongruous distractors were present for all participants, with overall recall from the Control condition from Experiment 1, where there was no added noise. There was a difference in the scores for Experiment 3 ($M = 60\%$, $SD = 17\%$) and the Control condition from Experiment 1 ($M = 69\%$, $SD = 12\%$); $t(65) = 2.50$, $p = 0.015$.

A direct logistic regression analysis was performed to test whether the distraction effect occurred at the site of the distracting noise or continuously during the lecture. Two predictors of correct recall were assessed: type of noise manipulation (laughter, whispering, crumpling paper, sinusoidal tone, silent pause as control) and location of target information in relation to the noise (just before a noise, just after a noise, or away from noise). We tested data on each of the 28 questions answered by 53 participants.

A test of the full model with all predictors against a constant-only model was not statistically significant, $\chi^2(6, N = 1{,}511) = 6.37$, $p = .38$, indicating that the predictors, as a set, did not reliably predict right and wrong responses on recall. Table 3 shows the logistic regression coefficient, Wald test, and odds ratio for each of the predictors and the constant in the equation.

According to the Wald criterion, neither location of noise nor type of noise reliably predicted right or wrong answers on recall.

Discussion

Comparing mean recall scores from Experiment 3 with mean recall scores from the control condition of Experiment 1 confirmed that added, discrete sounds incongruous with a lecture setting produced auditory distraction and impaired recall. Furthermore, the distraction effect was not limited to specific moments when distracting noises were heard, nor to any specific sound. This provides support for the interference-as-process hypothesis that distraction is a result of ongoing disruption of attention to a target speech stream, not momentary or sound-specific disruption. Said another way, the reason noises distracted in Experiments 1, 2, and 3 was not because they were either semantically or acoustically special and so drew attention at the moment they were heard, but because they produced a stream of information that shared enough grouping criteria with either the target stream or the environment stream that it became difficult to separate them, designate them as irrelevant, and inhibit them.

General Discussion

When it comes to potentially distracting noises, it is not the physical or even the semantic characteristics of the sounds that distract. Speech and laughter are sometimes especially problematic, and sometimes not, which effectively means they are not special at all outside of context. They have just the same processing-related potential for distraction as other noises, and depend on the environment and an individual's current objective for their effects. Auditory distraction is not a problem with noise, it is a problem of sense-making: Stimuli that are difficult to resolve as either part of the target auditory stream or part of the environment require increased processing, impeding encoding of new material, which results in impaired recall. Sounds that are clearly target-integral, or clearly non-target and environmental, do not.

In Experiment 1, we found that added fake laughter and an overlaid lecture impaired verbatim recall compared to other common environmental noises. In contrast, noise easily understood as part of the background resulted in similar performance to no noise at all. This was true whether the noise was linguistic (unintelligible group murmuring), non-linguistic but human (group shifting), or machine (construction noises). All of these noises resulted in similar recall performance to no noise because they were easily streamed as non-target, and inhibited.

In Experiment 2, we found that naturally occurring audience noise produced in response to a target speech stream resulted in little recall impairment. Recall in this condition was similar to recall in noise conditions where there was unintelligible speech (murmuring), other meaningless noise (construction noise, shifting), or no noise at all. Audience noises distracted when they were unusual or when they were heard in unexpected locations.

In Experiment 3, we examined whether a distraction effect of brief noises heard during the lecture was momentary or continuous, and whether it was a result of any specific kind of brief noise. When we spliced in short episodes of speech, laughter, and non-human noise at arbitrary locations in the lecture, we found that there was an overall recall impairment effect. This effect was neither local nor related to any particular noise, but continuous throughout the listening task. In all three experiments, we believe that the difficulty streaming auditory information in the distracted conditions was a result of auditory input failing to meet criteria for easy grouping as attended or inhibited stimuli. In Experiment 1, the language and laughter distractors were irrelevant, but they met enough criteria for grouping into the attended category that their processing drew on cognitive resources already enlisted in the processing of the target. The result was that organization and encoding of the target for memory suffered, but only to the degree where it was detected with verbatim recall tests. In Experiments 2 and 3, distraction effects and qualitative findings demonstrated that incongruity was important to distraction.

In our studies, listeners likely based target- and environmental-noise streaming on their experience with formal lectures and how audiences and speakers interact during such events. Failing to resolve elements of an auditory environment into a coherent picture would enlist increased organizational and structural processing resources to this resolution, drawing limited cognitive resources away from organizing and processing the target speech. The greater incongruity in Experiment 2 resulted in greater difficulty with recall. In Experiment 2, both verbatim information and gist was affected, while only verbatim information was affected in Experiment 1.

In sum, our findings support the interference-as-process hypothesis where auditory distraction results from the cognitive processing required to decisively sort sounds into attended and inhibited streams, regardless of the content of the sounds. We extend the interference-as-process hypothesis to include longer stimuli and more realistic environmental distractors. Our data also point to the likelihood of learned schema-related expectations of both an auditory scene and communicative behavior.

Importantly for applications of this research, the findings suggest that learning in complex environments with others is a multilayered and taxing enterprise, with work related to learning co-occurring with the ongoing work of maintaining an understanding of what is going on in the physical and social context. Distractors can be linguistic (distracting speech), paralinguistic (laughter), or non-linguistic (incongruous noises). The key is that distraction occurs because all information about one's environment is continually processed. All sounds are compared to a mental representation of the setting, including social components, with incoming information sorted into streams to be attended to and others to be inhibited. Increasing sorting difficulty can produce a cognitive load that may interfere with other attentional and processing work. A complete account of distraction and learning will take into account the many layers of this mental representation and the work necessary to maintain it.

Research on attention and learning that excludes the effort an individual exerts in making sense of the greater environment may gloss over an integral part of the learning experience. The result may be a body of research that is difficult to apply to real-world learning contexts. Further study of the relationships between social interaction, affect, learning contexts, attention, and cognition will do much to extend academic research in these areas as well as inform the work of instructors, students, and teacher educators.

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Table 1

Hypotheses, and Predictions, and Mechanism Across Experiments

Experimental Elements	**Experiment 1**	**Experiment 2**	**Experiment 3**
Hypotheses by Study	Not language, but sounds processed like language distract from language.	Expectations about how sounds should occur in context affect what distracts.	Auditory distraction is a result of a cognitive streaming process, not momentary shift of focus.
Task			
Listen to a 5-minute lecture and answer 20 multiple-choice questions after, testing recall of gist (content) and verbatim language (surface structure).			
Predictions	Among five environmental noises, artificial laughter and an added speech stream will distract.	Noises perceived as unrealistic will produce distraction effects.	Discrete incongruous noises will distract continuously.
	Recall of surface structure of language will be worse than recall of content.		
Mechanism			
Difficulty organizing and streaming sounds for attention or inhibition should produce distraction effects.			

Table 2

Mean Recall Scores (Standard Deviation) by Condition

Condition	*N*	Verbatim	Gist	Total
Control	33	71% (14%)	69% (14%)	69% (12%)
Laughter	37	59% (14%)	66% (17%)	63% (14%)
Overlaid Lecture	39	56% (17%)	63% (16%)	60% (15%)
Construction Noise	33	66% (14%)	65% (13%)	65% (12%)
Murmuring	36	68% (14%)	68% (18%)	68% (14%)
Shifting	38	65% (16%)	70% (18%)	68% (15%)

Table 3

Logistic Regression Predicting Correct Recall from Type of Noise Heard and Location of Target Information in Relation to Noise

Predictor	B	Wald χ^2	*p*	Odds Ratio
Type of Noise				
Laughter	-.16	.31	.58	.85
Whispering	.21	.52	.47	1.23
Crumpling Paper	-.33	1.30	.25	.72
Sinusoidal Tone	.05	.03	.87	1.05
Location				
Before Noise	.22	.95	.33	1.25
After Noise	.20	.79	.38	1.23
(Constant)	.36	30.11		

Table 4

Mean Recall Scores (Standard Deviation) by Condition

Condition	*N*	Verbatim	Gist	Total
Original TED Audio	63	67% (13%)	69% (18%)	68% (14%)
Heightened laughter	27	58% (21%)	59% (22%)	59% (20%)
Unusual noise	27	58% (16%)	57% (19%)	57% (15%)