Selection of goal-consistent acoustic environments by adults and children

Anonymous CogSci submission

Abstract

From birth and beyond, children are navigating a world with massive amounts of auditory input, sometimes relevant while other times purely noise, and must somehow make sense of it all. The early auditory environment is critical for building skills related to speech perception and recognition, auditory discrimination, and word learning, all of which support future language outcomes. What are still largely unknown are the strategies young children use to learn in even the noisiest environments. One such strategy is environmental selection, which allows children to seek environments that align with changing goals. In the current paper, we examined whether both children and adults make decisions about their environments by integrating both the auditory information and the current goal-state. While 3- and 4-year olds struggle with discrmininating speech streams at varying sound levels, 5-year-old children and adults can, and they use this information for environmental selection.

Keywords: active learning; auditory discrimination; auditory noise; cognitive development

Introduction

Children engage with their auditory environment from birth. These experiences support speech perception and language development. With relevant stimuli, however, also comes noise. Noise is both ubiquitous and unavoidable, from sounds as low as a whisper (30dB) to as high as crowded restaurants (90dB) (Erickson & Newman, 2017). Children struggle with speech perception and word recognition in noisy environments, and often require signal-to-noise (SNR) levels of 5-7dB higher than adults listening to the same stimulus (Bjorklund & Harnishfeger, 1990; Klatte, Bergström, & Lachmann, 2013). Despite this, children manage to make sense of such a noisy world. What strategies do they use?

More than 20 million children living in the United States are exposed to dangerous noise levels daily, and 5 million of those children suffer from noise-induced hearing loss as a result (Viet, Dellarco, Dearborn, & Neitzel, 2014). Unfortunately, children of color living in urban regions are overrepresented in these numbers (Casey et al., 2017). Chronic exposure to noise has been correlated with poorer reading performance, reduced short term and episodic memory, and smaller expressive vocabularies in elementary school children (Clark, Sörqvist, & others, 2012; Hygge, 2019; Riley & McGregor, 2012).Yet despite suboptimal conditions, language acquisition, cognitive development, and full engagement with the environment is still possible, albeit more difficult.

Children adjust their engagement with the environment when faced with suboptimal auditory patterns, even if this causes deleterious long- term outcomes. Cohen, Glass, & Singer (1973) measured the sound pressure levels in and around a noisy Manhattan high-rise apartment complex where 8- and 9-year-old middle class students lived. Auditory discrimination mediated the relationship between reading comprehension/ability and auditory noise. Children exposed to higher levels of auditory noise in the home eventually learned to filter the irrelevant auditory stimuli, but were doing so indiscriminately, such that they were also ignoring some important stimuli.

Given the importance of the early auditory environment and discrimination skills, children might also learn to optimize their auditory environments to successfully complete certain goals. For example, you might find that reading is best done in a library, not because of its convention (because libraries function as places to read/check out books), but because it is a quiet space. Such a strategy might allow children to exploit environmental variation in noise to maximize their ability to learn in suboptimal or variable conditions. In the current paper, we asked whether and how preschool children engage in active selection of the auditory environment to achieve a series of goals.

One way that both children and adults navigate such a complex world is through active learning: choices an agent makes to shape its own learning. The dominant approach to studying active learning has emphasized how learners approach individual stimuli. When faced with uncertainty, both human and machine systems can learn actively by choosing new stimuli to query that are informative with respect to the learner's current knowledge state (Castro et al., 2008). Infants, too, have been shown to use active learning strategies (Ruggeri, Swaboda, Sim, & Gopnik, 2019; see Xu, 2019 for review).

Although most active learning research has focused on stimulus selection, perhaps children and adults are engaging in active learning by also making decisions about the environments in which they learn. In practice, this behavior may present itself as moving to a different room to study for an upcoming exam or playing in a room with other children who seem to be having the kind of fun you desire. We might expect humans to seek out environments that best support their goals, and observe this strategy even in young children.

In the current paper, we asked whether children and adults actively select their auditory environment to achieve a series of goals. We conducted two experiments with both children and adults. Although our primary interest is whether and how children engage in environmental selection, we also collected adult samples to offer comparisons of how cognitively mature individuals might respond to these tasks. To ensure that the stimuli we use can be discriminated by children in our target ages, Experiments 1a and 1b investigate children and adults' auditory discrimination of noise in long speech streams. Experiments 2a and 2b then examine whether children and adults select auditory environments that match their goals.

Experiment 1a

Previous research has consistently shown that adults can discriminate when two different sounds are at or below 5db apart, and children as young as four perform similarly to adults as low as 5db (Jensen & Neff, 1993). However, the stimuli commonly used to measure auditory (or intensity) discrimination tend to be short tonal bursts. This might differ considerably from children's real-world auditory experiences, which are not always transient and which may reflect more chronic noise exposure. Additionally, noise exposure is not limited to nonspeech signals, so the stimuli we present in experimental sessions ought to reflect children's true encounters in their typical environments. As such, we played participants longer speech streams of up to 25s to determine whether their auditory discrimination skills hold under more complex constraints. We then asked participants to select the louder stimuli in a binary forced-choice paradigm.

Methods

Participants Experiment 1a measured adults' sensitivity to 5 SNR auditory signals of long speech streams. A total of 40 adults (mean age = 27.68 years; 52.5% Caucasian/White) living in the United States at the time of test were recruited to participate via the online platform, Prolific. Testing was restricted to a laptop, desktop, or tablet. All participants were fluent in English and had no severe visual or cognitive impairments. Informed consent was collected from each participant before the experiment began.

Figure 1: One of 10 animated classrooms participants viewed during the session.

Materials and Procedure Participants were told that they would watch 25-second animated videos from each of the ten classrooms in The Alphabet School, a fictional preschool program in which each class learns one letter of the alphabet from A-J. Each classroom consisted of 5-6 preschool children and one adult teacher with stereotypical male or female presentations. The wall colors of each classroom identified which classroom participants were viewing. In each video, the teacher would tell the students which letter of the alphabet they would be learning, followed by three images on a whiteboard of animals or objects that begin with that letter. Figure @ref(fig:e1-stimuli) illustrates one of the ten classrooms shown during the session.

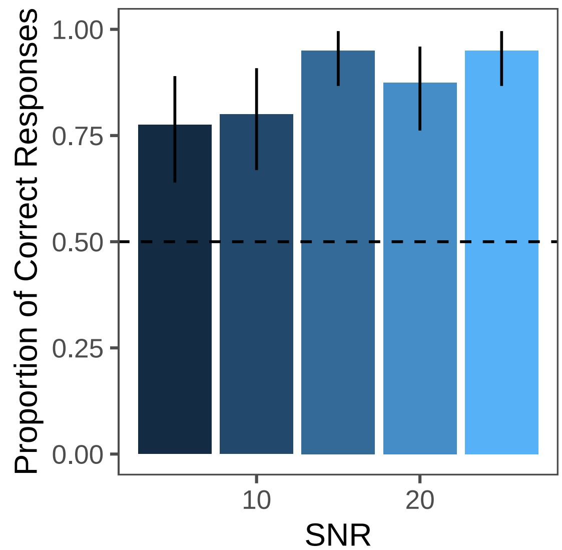

Figure 2: Results from Experiment 1a. Proportion of correct responses across SNR levels from 5–25dB. Error bars show 95% confidence intervals.

Participants viewed two videos per trial, for a total of five trials. Importantly, the classrooms differed in their signal-to-noise ratios (SNR), which ranged from 5-25dB. Each teacher's speech was registered at 65dB, and the background noise, a recording of live preschool classrooms collected by the first author, were equalized on speech subtracting any silence in the clips, and ranged from 35-60dB. As such, the two videos for each trial differed from 5-25dB from each other. The SNR levels of each classroom were counterbalanced across conditions. At the end of each trial, participants indicated which classroom was the louder of the two. To ensure that participants understood the referent of the question, we also asked at the end of the experiment whether the term "louder" referred to the loudness of the speaker or the loudness of the background noise. Additionally, to reduce participant inattention in the data, we included two attention check questions and excluded participants who answered at least one question incorrectly.

Results and Discussion

Given prior data, we expected that across SNR levels, adults would correctly identify relative differences in the auditory environments presented in this experiment. We preregistered a Bayesian mixed-effects logistic regression predicting correct responding as a function of SNR, with a maximal random effect structure (random slopes by SNR and a random intercept by participant). SNR level was centered at 15 dB. On average, adults were above chance across all five SNR levels (intercept: β = 2.15, 95% CrI = [1.64 - 2.9]), and there was a modest effect of SNR on performance (intercept: β = 0.08, 95% CrI = [0.02 - 0.16]). Data are shown in Figure @ref(fig:e1a-bar).

This finding is both a replication of previous studies which have found similar performance levels in adults, as well as an extension that revealed these findings hold even with more complex stimuli. These results affirm adults' auditory discrimination skills are fully mature, and that they possess the cognitive resources necessary to successfully complete this task. This study also offers a set of comparison data for Experiment 1b, which will test the same phenomenon in young children.

Experiment 1b

Methods

Experiment 1b

Participants Experiment 1b measured children's sensitivity to 5 SNR auditory signals of long speech streams.36 children (mean age = 4 years, 41.7% Caucasian/White) completed the same task as adults in Experiment 1a with a few notable differences. Those whose caregivers indicated they heard English at home less than 75% of the time were excluded from analysis.

Materials and Procedure Children were tested synchronously over the Zoom platform by an undergraduate research assistant. The researcher first collected informed consent from the caregiver, who was often present but instructed not to engage during the session, followed by assent from the child. Children whose caregivers pointed to the computer screen or provided answers during the session were excluded from analysis. Due to the age range of interest, the experiment was presented strictly though images and videos, and the research assistant verbally explained each slide to the children. Between trials, children were rewarded with virtual gold stars, which also served to pace the experiment and to maintain engagement. Finally, children were not asked to identify the referent of the question.

Results and Discussion

We anticipated that, while the strength of the effect would increase with age, all children would correctly identify relative differences in SNRs from 10-25dB, and that only three-year-old children would be unable to correctly identify this difference at 5dB. We ran the same Bayesian logistic regression presented in Experiment 1a, but entered in age (centered at the mean) as a main effect. Figure @ref(fig:e1b-bar) demonstrates a similar, though much weaker, pattern of auditory discrimination skills in preschool children. In the aggregate, 3-5-year-old children showed some discrimination ability on the current paradigm (intercept : β = -4.51, CrI = [-6.76 - -2.41]), but independent of SNR (intercept : β = 0.15, CrI = [-0.11 - 0.43]).

As expected, age plays a much larger role in these results than it does for adults. As such, we binned the data by age [3;0-3;11, 4;0-4;11, and 5;0-5;11 years] and ran the same analysis. Figure 4 illustrates an age effect, such that older children were more likely to correctly discriminate auditory signals than younger children (intercept : β = -3.14, CrI = [-4.9 - -1.52]).

While these findings diverge from previous work, there is no cause for concern. As described earlier, this task is much more challenging, and likely requires pooling more cognitive resources, which very young children don't yet possess. Additionally, the type of stimuli presented here differs from the tonal bursts or other brief nonspeech sounds used in earlier work. Taken together, our findings may expose some of the limits of auditory discrimination abilities in preschool children.

Experiment 2a

If participants can successfully discriminate between sound pressure levels, do they then use this information to inform which goals are most appropriate in these environments? Participants watched a video of a third-person character with several goals and were asked to select the environment that he should complete these goals. We hypothesized that adults would both consistently discriminate even the most challenging auditory signals given their mature cognitive system, and that children would show a developmental trajectory in both auditory discrimination and environmental selection. In other words, older children would perform similarly to adults on the auditory discrimination task and would show weaker, though similar performance on the environmental selection task.

Methods

Participants 126 adults (mean age = 27.82 years; 56.5% Caucasian/White) living in the United States at the time of test were recruited to participate via the online platform, Prolific. Testing was restricted to a laptop, desktop, or tablet. All participants were fluent in English and had no severe visual or cognitive impairments. Informed consent was collected from each participant before the experiment began.

Materials and Procedure Participants were introduced to a preschool-aged character named Ryan with eight goals to complete throughout the experiment- (1) to read a book, (2) to build a tower out of blocks, (3) to learn the letters of the alphabet, (4) to paint a picture, (5) to dance to his favorite music, (6) to learn a new language called Zerpie, (7) to talk to a friend, and (8) to eat lunch. All activities had relatively simple explanations with the exception of (6). For this trial, participants were told that Ryan's new neighbor, Logan, speaks a rare language called Zerpie, a language he doesn't speak. Ryan wants to learn Zerpie so he can communicate with Logan. For all activities, Ryan must complete each task in a closed room. Each goal was presented individually as a single trial for a total of eight trials. In each trial, participants watched a video in which Ryan stood in between two closed doors labeled "A" and "B", respectively. Before the video began, participants were told to watch and listen carefully to decide in which of the two rooms Ryan should complete his goal. As in Experiment 1, we manipulated the sound level of each room, but removed any classroom stimuli, including the teacher, and only allowed one child to open and stand in front of each door. As such, participants did not have access to any visual information of the room, and could only rely on auditory information, as well as any information provided by the character who opened the door. Each character's voice was equalized to 65dB and, unlike in Experiment 1, all characters shared the same voice. All characters except Ryan were preschool girls but differed in appearance. The same background noise in Experiment 1 was used for the current experiment, and the difference in SNR between the two rooms was 5-25dB. During the video, each character would open their respective door beginning with Room A. The character in Room A always said, "You can [goal] in this room", while the character in Room B always said, "Or you can [goal] in this room." While the room on the left was always labeled "A" and the room on the right was always labeled "B", the characters from and sound levels of each room, as well as goal order were counterbalanced across conditions. For each trial, participants were told which goal Ryan wanted to complete and were asked to select the room that he should complete his goal. After making a selection, they were then asked to briefly explain their choice. Responses for the quieter room (relative to the other and based on the actual sound pressure level) were given a 1, while responses for the louder room were given a 0.

Results and Discussion

We expected that adults would overwhelming select the quieter room when the goal was (1) to read a book, (2) to learn the new language called Zerpie, and (3) to learn the letters of the alphabet, but would be more likely to select the louder room when the goal was (1) to dance to his favorite music, (2) to talk to a friend, and (3) to build a tower out of blocks. Additionally, we expected participants to have no sound level preference for (1) eating lunch and (2) painting a picture. This is because the latter two activities might be more ambiguous in the degree to which a relatively quieter or louder environment supports or hinders the goal. We preregistered the following Bayesian mixed-effects logistic regression:

quiet ˜ activity + (activity | subject_id), where quiet refers to the number of times the quiet room was selected as the response, and both the activity in which participants were exposed and participants' individual responses were entered as random effects in the model. Figure 5 depicts adult participants' preferences for quieter environments based on the chosen activity. We found that all but two activities were either preferred in the quiet or loud room- eating (intercept : β = 0.1, Crl = [-0.5-0.8]) and talking (intercept : β = 0.5, Crl = [-0.06-1.2]), which were almost equally preferred in both rooms. Reading was most preferred in the quiet room while dancing was most preferred in the loud room.

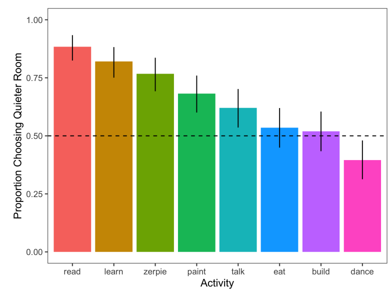

Figure 4: Experiment 2a. Proportion of participants selecting the quieter room by activity. Values closer to 1 on the y-axis indicate a preference for the quiet room.

These findings suggests adults are not only sensitive to differences in the auditory environment, but they also use these cues to reach certain goals. Moreover, adults are not indiscriminately selecting the quieter environment, but are instead taking into account the intention and explicitly weighing the auditory environment to do so.

Experiment 2b

In the next next study, we asked the extent to which 5-year-old children also weigh auditory information and goal-seeking to make decisions about optimal environments.

Methods

Participants [final number] 5-year-old children (mean age = 63.95 months, %% Caucasian/White) completed a truncated version of Experiment 2a to both prevent testing fatigue and to maximize any response differences based on the presented goals. In addition to testing children on the Zoom platform, we also recruited a small group of children at a Bay Area nursery school, which serves children 2-5 years old. This in-person testing was conducted with both caregiver consent and participant assent. As with the online testing, participants must have heard English at home at least 75% of the time and must have no cognitive, visual, or neurological concerns. Given the finding from Experiment 1b that 3- and 4-year-old children performed near chance in the auditory discrimination task with long speech streams, we chose to only test 5-year-old children for this portion of the study.

Materials and Procedure We tested children on the four activities with the widest differences observed in Experiment 2a- (1) to read a book, (2) to learn the letters of the alphabet, (3) to build a tower out of blocks, and (4) to dance to the music, a total of four trials. Additionally, participants in this experiment were only shown videos in which the two rooms had SNR differences of 25dB. This is because 5-year-old performance in Experiment 1b did not differ by SNR. The rooms and characters remained consistent with Experiment 2a, with one exception: the room labels, "A" and "B", were replaced with one black circle for Room 1 and two black circles for Room 2.. This change was implemented after finding that several participants in the pilot study seemed to favor the letter A over B, and because these letter labels may interfere with responses when the goal is to learn the letters of the alphabet. Black circle labels, on the other hand, are more abstract and may reduce this bias. As done previously, the characters, sound pressure levels, and goal order were counterbalanced across conditions. Whether testing online or in-person, participants were shown the same set of videos and a research assistant (for online testing) or the first author (for in-person testing) verbally explained each slide and video to participants. After watching each video, participants were asked to select the room Ryan should complete his goal and to briefly explain their response. As in Experiment 2a, responses for the quieter room (relative to the other and based on the actual sound pressure level) were given a 1, while responses for the louder room were given a 0.

Results and Discussion

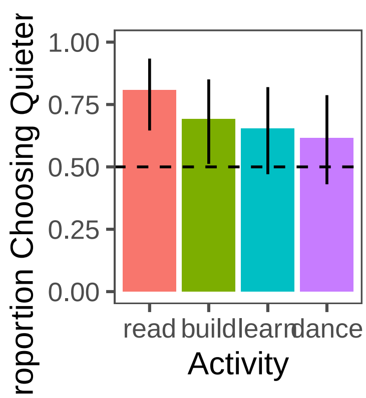

Figure 5: Experiment 2b. Proportion of participants selecting the quieter room by activity.

We expected to see a similar, though weaker, response pattern as adult participants in Experiment 2a. Figure 6 depicts childrens' preferences for quieter environments based on the chosen activity. We ran the same logistic regression as in Experiment 2a, but added age as a main effect. As expected, children were more likely to select the quieter room for book reading and learning the letters of the alphabet.

These findings propose that 5-year-old children are using a separate strategy from adults by selecting the quieter room more often regardless of the goal.

General Discussion

These set of experiments demonstrate both an important relationship between auditory discrimination and a strategy children and adults use to optimize their auditory environments and achieve goals. Experiment 1a and 1b found that adults and older children can sufficiently discriminate auditory stimuli in long speech streams at sound pressure levels as low as 5dB. The challenge we observed in 3- and 4-year-old children's performance may reveal a lack of cognitive skills necessary to complete the task. The fact that 5-year-old children were performing above chance, however, may indicate that these skills are rapidly maturing by the fifth year of life. Experiment 2a displayed adult's selectivity of auditory environments based on changing goals while Experiment 2b demonstrated the opposite; 5-year-olds were more likely to select the quieter room regardless of the stated goal.

The latter finding does not necessarily reveal a failure on children's end, but rather a useful heuristic they might employ when they are still learning about much of their world. Whereas most adults have the flexibility of basic linguistic and cognitive mastery to seek louder environments for certain tasks, children can reduce uncertainty by selecting quieter auditory environments and then focus their attention and cognitive energy on achieving them. Previous work has shown that humans (including children) have an intrinsic desire to reduce uncertainty (Gottlieb, Oudeyer, Lopes, & Baranes, 2013). In the wild, children pursue ways to reduce uncertainty when faced with a possible reward (Feldstein & Witryol, 1971) and search for additional information on a particular topic when their intuitive theories are less informative (Wang, Yang, Macias, & Bonawitz, 2021). Thus, this experiment may offer another example of uncertainty reduction in children.

By understanding the strategies children use to learn in noisy auditory environments, we might offer better solutions for those exposed to chronic noise, thereby mitigating some of its negative effects. This is becoming more and more critical as cities become more populated (bringing construction with it) and auditory noise becomes even more unavoidable. Future studies will need to (1) explore the developmental trajectory of environmental selection such that we can identify when indiscriminately selecting the quieter environment is no longer beneficial, and (2) examine the boundaries of environmental selection by probing these questions with other goals and in other contexts (e.g. first-person goal-setting). Investigating how children learn in noise will ultimately bring us closer to understanding the complex wonders of childhood.

Acknowledgements

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