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Building Categories to Guide Behavior: How Humans Build and Use Auditory Category Knowledge Throughout the Lifespan

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BUILDING CATEGORIES TO GUIDE BEHAVIOR: HOW HUMANS BUILD AND USE AUDITORY CATEGORY KNOWLEDGE THROUGHOUT THE LIFESPAN

By

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Abstract

Although categorization has been studied in depth throughout development in the visual domain (e.g., Gelman & Meyer, 2011; Sloutsky 2010), there is little evidence examining how children and adults categorize everyday auditory objects (e.g., dog barks, trains, song, speech) or how category knowledge affects the way children and adults listen to these sounds during development. In two separate studies, I examined how listeners of all ages differentiated the multidimensional acoustic categories of speech and song and I determined whether listeners used category knowledge to process the sounds they encounter every day. In Experiment 1, listeners of all ages were able to categorize speech and song and categorization ability increased with age. Four- and 6-year-olds were more susceptible to the musical acoustic characteristics of ambiguous speech excerpts than 8-year-olds and adults, but all ages relied on F0 stability and average syllable duration to differentiate speech and song. Finally, 4-year-olds that were better at categorizing speech and song also had higher vocabulary scores, providing some of the first evidence that the ability to categorize speech and song may have cascading benefits for language development. Experiment 2 demonstrated the first evidence that listeners of all ages have change deafness. However, change deafness did not differ with age, even though overall sensitivity for detecting changes increased with age. Children and adults had more error for within-category changes compared to small acoustic changes, suggesting that all ages relied heavily on semantic category knowledge when detecting changes in complex scenes. These studies highlight the different roles that acoustic and semantic factors play when listeners are categorizing sounds compared to when they are using their knowledge to process sounds in complex scenes.

Table of Contents

List of Tables

List of Figures

Building categories to guide behavior: How humans build and use auditory category knowledge throughout the lifespan.

Chapter 1: Introduction

At any moment, a multitude of sounds are arriving at a listeners' ears, and together these sounds create a rich representation of the surrounding acoustic landscape. When adults listen to acoustic scenes, attention is primarily object-based (Duncan, 2006; Shinn-Cunningham, 2008), with both the object's physical characteristics and the object's semantic category contributing heavily to how they attend to and make sense of their surroundings (e.g., Gregg & Samuel, 2009). Categorization is evident when adults treat acoustically dissimilar sounds as equivalent (Massaro, 1987). This skill is an important tool in adults' cognitive and perceptual repertoire because it aids in memory storage and retrieval and it can also guide behavior when new exemplars of a category are encountered (Gelman & Meyer, 2011). Yet, categorization is not just a feature of processing in adulthood. From their first months, infants can categorize a wide array of sights and sounds around them, including speech sounds, like /ba/ and /pa/ (Kuhl, 1983; Werker & Tees, 1984), and visual objects, like fish, dinosaurs, and cats (Fulkerson & Waxman, 2007; Quinn, Eimas, & Tarr, 2001).

Categorization is an important skill especially for young listeners who are still in the process of organizing and making sense of the sounds around them (Bornstein & Arterberry, 2010). The ability to rapidly categorize objects can be important for highlighting relevant features and ignoring features that are not diagnostic of a category. For instance, when children are categorizing animals, they extend the category based on the shape and texture of novel objects, whereas only shape is important when categorizing novel artifacts (Booth & Waxman, 2002; Jones & Smith, 2002). Similarly, children rely on color more than shape when determining

similarity in foods, but when the same objects are described as toys, children rely on shape more than color (Macario, 1991). Thus, children are able to learn the features that are most diagnostic or predictive of a given category and can selectively attend to those features when extending categories to novel objects in different contexts.

Although there is a rich literature examining categorization for a range of visual objects throughout development (e.g., Ahissar & Hochstein, 2004; Gelman & Davidson, 2013; Sloutsky, Lo, & Fisher, 2001), there is relatively little research examining how these factors influence the way adults, and especially children, process everyday auditory objects (but see Berland et al., 2014; Gygi, Kidd, & Watson, 2007; Gygi & Shafiro, 2011; Krishnan, Leech, Aydelott, & Dick, 2013). Indeed, the majority of the research examining auditory categorization during development comes from consonant and vowel categories in speech perception (e.g., Holt & Lotto, 2010). In these studies, categorization often depends on the distribution of sounds along a single dimension like voice pitch, formant frequency (i.e., peak resonating frequencies of the vocal tract), or voice onset time (VOT; time between burst and voice onset). Even though adults seem to rely heavily on forming categories based on a single informative dimension (e.g., Idemaru & Holt, 2011), many natural categories are multidimensional in nature and require the listener to base their responses on multiple features or on a conjunction of dimensions (Ashby & Maddox, 1990).

In auditory human communication, speech and song are two classes of human communicative utterances that differ on a number of dimensions. Song is typically more rhythmically regular, has a more stable fundamental frequency (F0), has longer utterances, and is higher in pitch than speech (e.g., Vanden Bosch der Nederlanden, Hannon, & Snyder, 2015a). Thus, these categories are not likely to be differentiated based on any single dimension, but as a

result of a combination of dimensions. In terms of their function, speech is considered to be particularly well-suited for the transaction of meaning or propositional thought, such as describing who is doing what to whom. In contrast, song is especially well-suited for emotional regulation, as demonstrated by its pervasive presence in mother-infant interactions (Trehub & Trainor, 1998), for regulating emotional stress in adolescence (Miranda, 2013), or for relieving stress in the hospital (Thoma et al., 2013). Music also facilitates joint action by providing a strong rhythm for coordinating the movements of several individuals as in work songs or marches (Jackendoff, 2009). Thus, many categories, including speech and song can be differentiated by both perceptual similarity and by their function or status.

Yet, when adults direct their utterances toward infants, the lines between speech and song are blurred. Infant-directed (ID) speech is more rhythmically regular and higher in pitch than adult-directed speech, and researchers have described that the melody is the message for ID speech (Fernald, 1989). Even in terms of emotional valence and intensity, ID speech and song overlap and adults and infants perceive infant-directed utterances as more positive and more loving than adult-directed utterances (Corbeil, Trehub, & Peretz, 2013; Trainor, Austin, Desjardins, 2000). Thus, it may take time for the developing listener to categorize speech and song as two distinct multidimensional auditory categories.

There is no research that examines whether children or adults can categorize speech and song (but see Monson, Lotto, & Story, 2012), and, yet, there is a considerable amount of literature within each domain in isolation. Children have a large vocabulary and sophisticated knowledge of syntax by age 3, although there is still significant language development from age 3 through age 8 in terms of grammar and vocabulary (Biemiller & Slonim, 2001; Marcus et al., 1992; Tomasello, 1999). In music, infants possess many of the skills required to perceive a

melody in terms of pitch and rhythm discrimination, but culture-specific musical abilities, like harmonic expectancies or metrical structure, are still being learned and are quite malleable in early childhood through age 7 (Trainor & Trehub, 1994; Hannon et al., 2012). Given the considerable experience children have engaging in music and language, children may differentiate speech and song from an early age, which would result in no developmental differences in the ability to categorize speech and song with age.

However, children are not always adept at teasing apart the manner in which a sentence is uttered from the content of the utterance. For instance, a neutral emotional sentence like "Today is Wednesday" could be said in a happy way, with a fast rate of speech and high pitch, or in a sad way, with a slow rate of speech and low pitch. When 4- to 10-year-olds were asked to rate the overall emotion of a sentence with incongruent semantic and acoustic content, 4-year-olds exclusively used sentence content, whereas adults and older children (8-10) primarily relied on paralanguage, or the way the sentence was uttered (Friend, 2000; Morton & Trehub, 2001). Similarly, five- to ten-year-olds also based their ratings on the semantic content of songs, even though adults rated emotion based on melodic cues (e.g., slow tempo, minor key) for the same text (Morton & Trehub, 2007). Children have trouble integrating the semantic content of words with the manner in which they were uttered for both spoken and sung utterances. These results suggest that children's limited attentional resources are captured by lexical content, which overshadows prosodic and melodic cues to expressive qualities of speech and song. As such, it is possible that children may have trouble identifying whether or not an utterance was spoken or sung due to their pre-occupation with semantic content of novel utterances.

The goal of Experiment 1 was to examine whether 4- to 8-year-old children and adults could categorize speech and song. Speech and song are of particular interest because the input

children receive changes over time, which means that children must learn to distinguish speech from song as they encounter a larger proportion of adult-directed compared to infant-directed speech. Thus, I examined whether children could categorize speech and song when utterances were carefully controlled for acoustic, semantic, and emotional factors. Speech and song were matched in average pitch, total duration, and semantic content, but they differed in F0 stability and syllable duration. Thus, although pitch height and overall duration varied within each group of the speech and song exemplars used for the current study, song had more stable F0 than speech. Using these carefully matched spoken and sung utterances, I examined whether categorization ability changed with age (Aim 1). As described above, learning categories can facilitate the processing of category-relevant features for animals, foods, and artifacts. Similarly, categories for speech and song may be important for organizing and processing human communicative utterances. Of course, it is also possible that categorizing speech and song and applying category-specific knowledge rely on separate underlying processes. Further, even if category knowledge is present, it may take time for children to learn to apply their knowledge of speech and song in a context-specific manner. As such, it is important to characterize whether the ability to categorize speech and song is related to language proficiency. I examined whether children's speech and song categorization ability was related to language learning in particular, as indexed by vocabulary, or whether categorization ability was primarily related to general cognitive abilities, as indexed by standardized measure of fluid intelligence (Aim 2).

Although children may be able to categorize these carefully matched exemplars of speech and song, it would be interesting to examine how children and adults perceive the musical characteristics of ambiguous utterances. Thus, another goal of Experiment 1 was more exploratory in nature and examined how children and adults categorized ambiguous utterances

that vary on a number of acoustic, semantic, and emotional factors (Aim 3). To examine this question, listeners also categorized two classes of ambiguous utterances, ID speech and auditory illusions from speech to song (called illusions). Auditory illusions are speech utterances that have relatively stable F0 for each syllable, like song (Tierney et al., 2012). When auditory illusions are repeated several times in succession, listeners with a range of musical abilities perceive them as transforming from speech to song (Deutsch et al., 2011; Tierney et al., 2012; Vanden Bosch der Nederlanden et al., 2015a). As outlined above, ID speech is often described as musical speech due to the presence of song-like features, including high pitch, long utterances, and heightened emotional intensity (e.g., Corbeil et al., 2013). Ambiguous utterances are particularly important for examining what factors drive categorization at different stages of development. In particular, factors like high pitch, long syllable durations, stable F0, and emotional intensity may be more predictive of song earlier in development as children are still learning what features are most diagnostic of song and speech. In families with young children, song is used to make daily routines special, fun, and engaging (Custodero, 2006). Therefore, it is possible that children may perceive acoustic correlates of positive or intense emotions, such as high pitch, as sounding more song-like. Thus, to examine what features are most predictive of song responses at each age group, all acoustic and emotional factors that have been described in previous research as being related to song will be used to predict the proportion of song responses for all ages (Aim 4).

Given the considerable amount of experience children have with music and language during their first years, it was hypothesized that children would be able to differentiate speech and song already at 4 years of age. It was also hypothesized that categorization performance would increase with age as a result of increased understanding of the differences between speech

and song, but also as a result of increased integration of paralinguistic and semantic information (e.g., Morton & Trehub, 2001). It was also anticipated that children's categorization ability would correlate with their vocabulary, given previous evidence in the visual domain that well-formed categories could have cascading effects on the ability to process category-relevant features (e.g., Macario, 1991). Finally, it was hypothesized that 4- and 6-year-olds would rate the musical acoustic characteristics in ambiguous utterances as more song-like than older listeners, because younger children are presumably still learning to differentiate speech and song. It was also anticipated that older children and adults would rely on F0 stability and rhythmic regularity, while children would rely on these and additional acoustic features, again, as they develop more distinct categories for speech and song.

Chapter 2: Experiment 1

Methods

Participants

A total of 56 listeners (14 from each of the following age groups: 4-year-olds, 6-year-olds, 8-year-olds, and undergraduate adults) participated in the sorting task[1] and all 42 children also participated in a standardized IQ task for a total of one hour of participation. Adults did not participate in the IQ subtests because their performance on the categorization task was anticipated to be at ceiling. On average, 4-year-olds (6 males) were 4.48 years old (standard deviation: .23 years), 6-year-olds (6 males) were 6.47 years old (sd: .24 years), 8-year-olds (6 males) were 8.48 years old (sd: .29 years), and adults (7 males) were on average 20.2 years of age (sd: 1.96 years). No age groups had significant music training, but on average 4-year-olds had 1.3 months (sd: 3.5 months), 6-year-olds had 3 months (sd: 7.3 months), 8-year-olds had 7.5 months (sd: 11.8 months), and adults had 11.8 months (sd: 19.0 months) of musical training. All participants were fluent English speakers, although two 4-year-olds, five 6-year-olds, one 8-year-old, and four adults were bilinguals. One additional 8-year-old and five 4-year-olds were excluded because they did not finish the task (N=5) or because they pressed only one button for all trials (N=1). Children were recruited from the Las Vegas area and received a small prize/toy and certificate for their participation. Adults were recruited from the University's psychology

[1] Power analyses, calculated using G Power, indicated that 8 participants per group would be sufficient for a significant within-subjects effect of speech compared to song (estimated η_p^2 = .8). Additional power analyses indicated that 13 participants per group were required to find a significant effect for correlational analyses (estimated r^2 = .65). Thus, we chose 14 participants for each age group so that the side of the box that was for the play and the musical could be counterbalanced.

subject pool. All listeners reported normal hearing at the time of testing. All participants or caregivers provided informed consent before participation and children provided assent to participate. The University's Institutional Review Board approved all materials.

Apparatus

All participants were tested individually in a quiet room using a MacPro4.1 running Windows 7 Enterprise. Stimuli were presented using a custom script in Presentation (16.3), with images displayed on a Samsung SyncMaster XL2370 23-inch monitor. Listeners heard sounds presented through headphones. Children heard sounds at about 60 dB SPL (sound pressure level) through KidzGear headphones and adults used Sony MDR-7506 Professional headphones. A custom Presentation script recorded computer keyboard presses made by the experimenter and participants indicated their responses to the experimenter by sorting a large laminated "sound card" into one side of a "sound sorting box" (i.e., shoe box) labeled "Play" or "Musical" (see Procedure).

Stimuli

Four types of stimuli were used for the current experiment: speech, song, ID speech, and illusions. Speech and song stimuli were designed to address categorization ability when several features were controlled, including semantics, overall pitch, and duration, so that factors that are considered more song-like did not 100% covary. The two ambiguous utterance types were not controlled for these features and were meant to index how song-like acoustic and emotional factors in natural spoken utterances affected listeners' speech and song categorization. All utterances are compared here to understand how they differed from one another, but overt (speech and song) and ambiguous (ID speech and illusions) utterances were analyzed separately in the results section because these groupings differ from each other in many ways.

For ambiguous utterances, female ID speech samples were provided through personal communication with S. Trehub and J. Plantinga and were excerpts of infant-present, infant-directed speech. Male ID speech excerpts were recorded by the parent in a natural play setting with instructions to refrain from singing, much like Nakata & Trehub (2004). Ambiguous speech excerpts were provided with permission from A. Tierney, but were originally obtained from free online audio book websites (librivox.org and audiobooksforfree.com). As such, only male recordings could be obtained for this group of ambiguous utterances.

Overt speech and song samples were recorded for the current study using a ZOOM H4next Audio Recorder inside a sound-attenuated booth. Samples were recorded at 44.1 Hz and 16-bit depth. The author created 15 spoken contours from Harvard sentences (see Appendix 1; IEEE Subcommittee, 1969) to match the average pitch and duration of spoken and song sentences as closely as possible. To create these stimuli, sentences were first spoken and recorded by the author in an emotional manner in order to create a natural sentence contour with a wide pitch range. Next, while trying to preserve that natural sentence contour, the author sang and recorded a melodic contour that fit well with the spoken sentence contour. Four actors/singers (2 males and 2 females) mimicked the 15 pre-recorded spoken and sung Harvard sentences and provided several exemplars of each sentence. Creating spoken and sung exemplars in this manner allowed for the examination of acoustic features that lead to successful categorization of speech and song, without the possibility that stimuli could be categorized solely based on features that were not reliable markers of speech and song categories, such as average pitch or overall duration. All segments were normalized to -35 dB Total RMS amplitude and were presented at approximately 60 dB SPL to participants through headphones.

To understand how stimuli differed in subjective dimensions of emotionality and intended audience, five participants each rated all 60 excerpts according to the excerpt's overall emotional valence (1 = negative, 2 = neutral, or 3 = positive) and emotional intensity (1 = not emotional to 5 = very emotional). To validate that ID speech differed from other utterances, these same participants rated whether or not each excerpt was intended for an infant or an adult (responded "I" = infant or "A" = adult). Results are displayed in Table 1, below. ID speech was perceived as less adult-like, more emotionally intense, and more positive than all other sound types (all p's < .01), which is consistent with previous research cited above. These results also confirmed that these ID speech excerpts were representative of this type of utterance. Illusions were rated as more adult-like, less emotionally intense, and less positive than all other types (p's < .01), except for speech (intensity: p = .145; valence: p = .126). This confirmed that illusions were representative of typical adult-directed speech and that the speech exemplars created for the current experiment were similar in terms of emotional content to natural speech excerpts. Speech and song excerpts did not differ from each other in terms of overall emotional valence (p = .123) or intensity (p = .191), but speech was rated as more adult-directed than song (p = .005). Thus, overt spoken and sung excerpts could not be categorized by overall emotional valence or intensity and illusions differed from ID speech on all measures.

Stimulus Group	Percentage "Adult" responses	Emotional intensity rating	Emotional valence rating
Song	40 (8)	2.8 (.33)	2.3 (.26)
Speech	59 (21)	2.5 (.59)	2.1 (.42)
Illusions	97 (7)	2.2 (.48)	1.9 (.34)
ID Speech	11 (15)	3.3 (.55)	2.7 (.3)

Table 1. Participants' responses for emotional intensity, emotional valence, and intended listener. Although illusions and ID speech differ on emotional intensity and valence, overt song and speech cannot be categorized by these factors alone.

Several acoustic characteristics were also analyzed for each sentence, allowing for the assessment of group-level acoustic differences (see Table 2). Fundamental frequency (F0) was calculated using Praat's autocorrelation function (Boersma & Weenink, 2010) after the floor and ceiling Hertz (Hz) levels were determined using the procedure and plug-in suggested by DeLooze and Hirst (2008) called Momel-Intsint (Hirst, 2005). This procedure improved the calculation of F0 and prevented octave transposition errors common to pitch measurement software. Syllable, vocalic, and intervocalic intervals were marked by hand by the experimenter using Peterson and Lehiste's (1982) guidelines for phonemic segmentation. Vocalic Normalized Pairwise Variability Index (vNPVI) is a standard measure of speech rhythm and was calculated according to the formula provided by Grabe and Low (2002). F0 stability was calculated for each sentence segment by taking the standard deviation of the F0 in semitones (St) for each syllable and then by taking the average of the standard deviations across all syllables in an utterance. Note that larger values of F0 stability indicate less stability. F0 range was calculated by subtracting the minimum F0 recorded in an utterance from the maximum recorded F0 of the same utterance.

Stimulus group	F0 (Hz)	Syllable F0 stability (SD St)	Syllable duration (ms)	Total duration (s)	Range (St)	vNPVI
Song	199.3 (68.7)	.73 (.33)	274 (50)	2.611 (.45)	9.9 (2.6)	64.4 (19.1)
Speech	196.0 (68.6)	1.3 (.17)	253 (48)	2.442 (.34)	14.0 (2.3)	57.1 (16.9)
Illusions	139.6 (46.6)	.90 (.30)	205 (74)	1.289 (.27)	9.7 (1.6)	66.1 (23.8)
ID speech	235.2 (48.8)	1.6 (.75)	491 (383)	1.579 (.70)	14.2 (4.7)	65.7 (19.9)

Table 2. Acoustic characteristics averaged by stimulus group.

Song and speech did not differ in average F0, average syllable duration, total duration, or vNPVI (p's > .1). However, speech had a larger F0 range and had less F0 stability than song (p's < .01). Although it is initially surprising that the total range is larger in speech than song, this is likely due to creating speech stimuli that had the same average F0 as sung utterances. Illusions and songs were not different in their average range (p = .855) and ID speech and speech were not different from each other in terms of range (p = .892). Greater F0 stability for song compared to speech is consistent with previous literature (Tierney et al., 2012). It is also of interest to note that for F0 stability, all utterance types were significantly different from one another, except ID speech did not differ from speech (p = .070) and illusions did not differ from song (p = .305). Illusions were lower in F0 overall (p's < .05), likely because this group was comprised of only male voices. ID speech was higher in pitch than illusions (p < .001) and marginally higher than speech (p = .075), which is consistent with previous work comparing adult-directed and infant-directed speech (Fernald, 1989). ID speech also had significantly longer average syllable durations than all other groups (p's < .01). Finally, there were no group differences in vocalic nPVI (p = .575). Thus, although speech and song are matched on a number of characteristics,

they differed in F0 stability and F0 range. Ambiguous utterances differed from one another on all reported measures except for total duration and vNPVI, and ID speech utterances were more similar acoustically to overt speech, whereas illusions were more similar to overt song.

Procedure

All listeners were given a story about Frankie, a sound engineer, who recorded sounds for a play and for a musical. Frankie needed to get the recorded clips back to the actors so that they could practice, but all the sound files were mixed up on the computer. All participants were asked to help Frankie sort the sounds by putting each sound file (a laminated card) into the correct part of a sound-sorting box. Instead of physically sorting laminated cards, adults simply pressed "M" for musical and "P" for play on the keyboard. Listeners were first trained on the procedure using overtly spoken Harvard sentences and overtly sung children's songs (see Appendix 1). During training, participants were told that if someone was singing, the sound card belonged in the musical and if someone was speaking/talking the sound card belonged in the play. Training was repeated if participants failed to understand the difference between utterances that belonged in the play or the musical. The sorting task was split into 4 smaller blocks with 15 sounds in each block, but speech, song, ID speech, and illusions were presented in a random order chosen by Presentation software. A trial consisted of two presentations of one of the 60 utterances and then a prompt to sort the sound into the side of the box that was for the play or the side of the box that was for the musical. The side of the box dedicated to the musical and the play was counterbalanced. Upon completion of the sorting task, children began the Vocabulary and Matrix Reasoning subtests.

Results

In order to assess categorization performance, the proportion of trials in which participants responded "song" were recorded for each utterance type. As described above, overt speech and song were analyzed separately from ambiguous utterances due to their acoustic, emotional, and semantic differences. The proportion of song responses was submitted to a 2 x 4 (Utterance Type [song, speech] x Age [four, six, eight, adult]) mixed design Analysis of Variance (ANOVA) with utterance type as a within-subjects factor and age as a between-subjects factor. A main effect of utterance type was found, $F(1, 52) = 519.59$, $p < .001$, $\eta_p^2 = .909$, with more song responses on song trials (87.2%) than speech trials (15.4%; see Figure 1). There was a main effect of age, $F(3, 52) = 4.66$, $p = .006$, $\eta_p^2 = .212$, such that the overall proportion of song responses increased with age. However, planned comparisons revealed that even though 4-year-olds had fewer song responses than all other ages (p's < .02), all other age groups did not differ from one another ($p > .353$). Age also interacted with utterance type, $F(3, 52) = 6.20$, $p = .001$, $\eta_p^2 = .263$, and planned comparisons indicated that there was no difference in the proportion of song responses for speech trials across age groups ($p = .698$), but there was an increase in the proportion of song responses with age for song trials, $F(3, 52) = 9.84$, $p < .001$, $\eta_p^2 = .362$, which can be seen in Figure 1. Thus, all age groups were able to categorize speech and song, but their ability to categorize song increased with age ($r = .45$, $p < .001$).

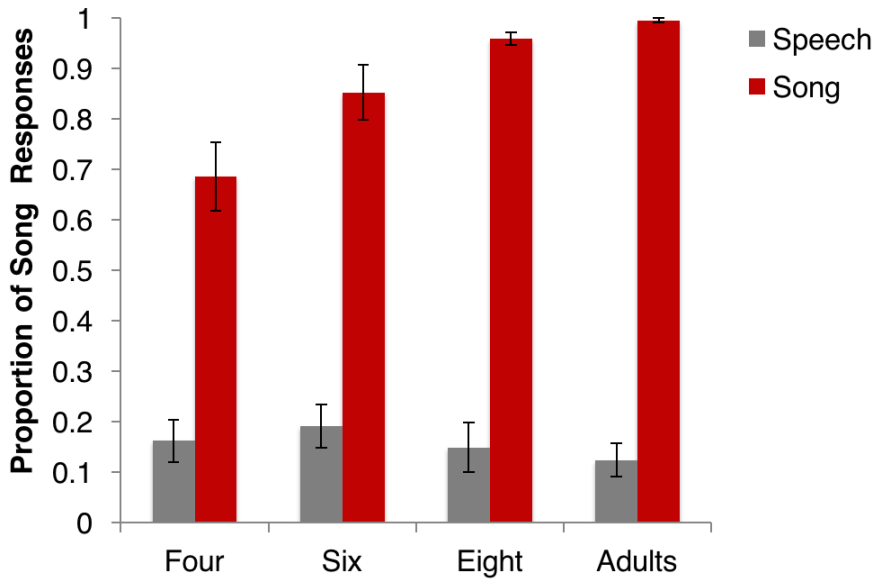

Figure 1. Proportion of song responses for overt speech and overt song utterance types for all age groups. Listeners became better at categorizing song with age, but not speech.

To further understand how overall speech and song categorization ability changed with age, the proportion of song responses on overt song trials was subtracted from the proportion of song responses on overt speech trials. This song-speech difference score gives a better estimate of overall categorization performance than simply looking at the rate of responding song for each utterance type. Categorization performance increased with age, $F(3, 52) = 6.20$, $p = .001$, $\eta_p^2 = .263$, as is clear in Figure 2. In particular, 4-year-olds were significantly worse at speech-song categorization than 8-year-olds ($p = .002$) and adults ($p < .001$) but not 6-year-olds ($p = .127$), 6-year-olds were worse than adults ($p = .022$) but not 8-year-olds ($p = .093$), and 8-year-olds were not different from adults ($p = .524$; see Figure 2). These results indicated that speech-song categorization changed with age and reached adult-like levels by age 8. Thus, even though all ages were able to categorize speech and song, this skill took time to fully develop.

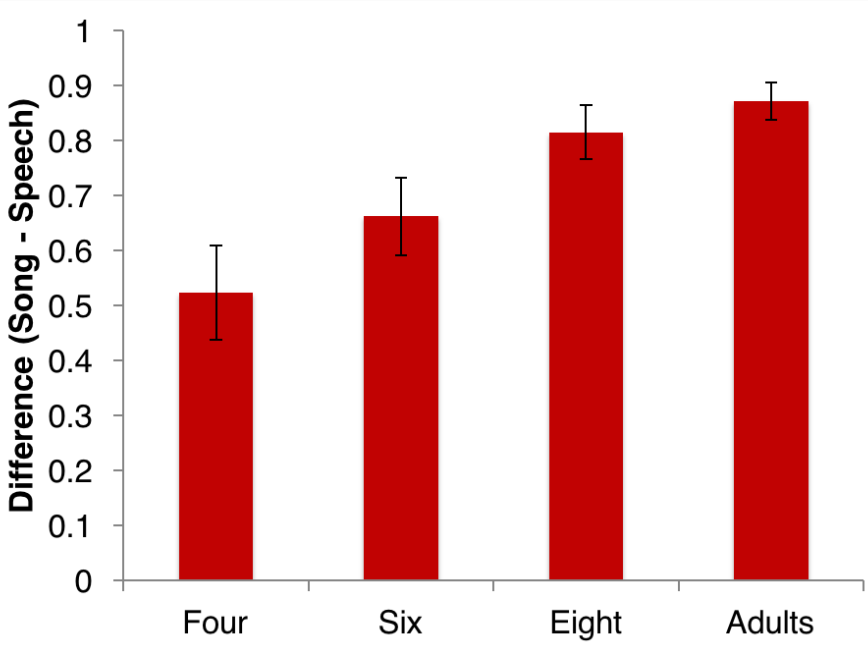

Figure 2. Speech-song difference scores for each age group indicated that categorization ability increased with age.

Speech and song categorization ability was compared to vocabulary and fluid intelligence by correlating children's raw scores for the two WASI subtests with speech-song difference scores for each age group separately. Speech-song categorization ability was significantly correlated with 4-year-olds' vocabulary, $r(12) = .676$, $p = .008$, but not their matrix reasoning subtest scores, $r(12) = .043$, $p = .885$, as is evident in Figure 3. No correlations with speech and song categorization were evident for 6-year-olds' vocabulary, $r(12) = .406$, $p = .150$, or matrix reasoning, $r(12) = .377$, $p = .184$, or for 8-year-olds' vocabulary, $r(12) = -.148$, $p = .614$, or matrix reasoning, $r(12) = .429$, $p = .126$. Although speech and song categorization did not correlate with vocabulary and fluid intelligence for most age groups, there was a strong correlation between vocabulary and speech-song categorization for 4-year-olds. These results suggest that 4-year-olds who were better at teasing apart speech and song also had better verbal abilities, providing some of the first evidence that well-formed categories for speech and song is related to language learning.

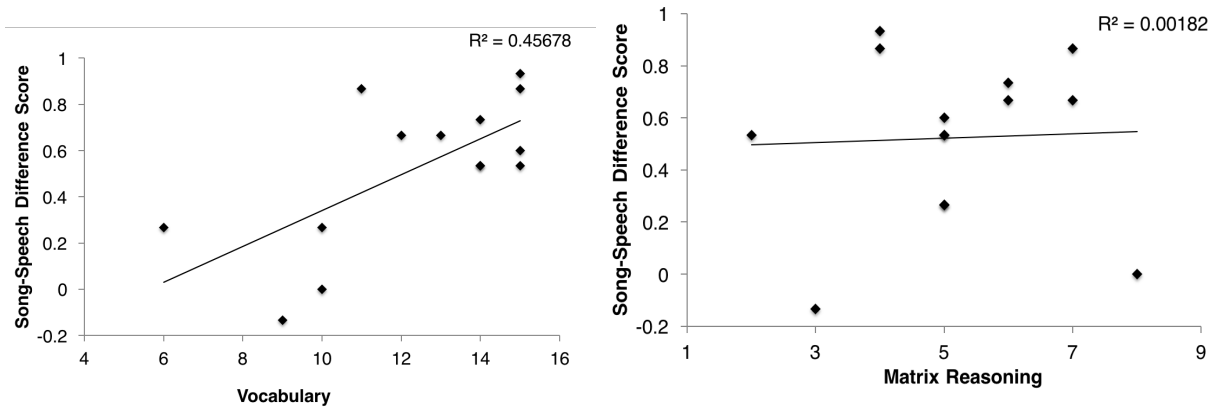

Figure 3. Four-year-olds' speech-song categorization ability for vocabulary and matrix reasoning subtests. Only vocabulary correlated with speech-song categorization ability.

To analyze ambiguous utterances, the proportion of song responses were submitted to a 2 x 4 ANOVA with utterance type (illusions, ID speech) and age (4, 6, 8, adult) as within and between subjects factors, respectively. There was a main effect of utterance type, $F(1, 52) = 86.24$, $p < .001$, $\eta_p^2 = .624$, with a greater proportion of song responses for illusions (24.9%) than ID speech (5.5%; see Figure 4). There was also a main effect of age, $F(3, 52) = 6.63$, $p = .001$, $\eta_p^2 = .277$, such that 4- and 6-year-olds had a larger proportion of song responses than 8-year-olds and adults (p's < .05). The two youngest ($p = .196$) and the two oldest ($p = .767$) age groups did not differ from each other. Finally, age interacted with utterance type, $F(3, 52) = 3.91$, $p = .014$, $\eta_p^2 = .184$, with a slightly stronger effect of age for illusions, $F(3, 52) = 6.07$, $p = .001$, $\eta_p^2 = .259$, than ID speech, $F(3, 52) = 3.95$, $p = .013$, $\eta_p^2 = .186$. Further, the proportion of song responses for illusions and ID speech were significantly above zero for all age groups (p's < .05), except for adults' responses for ID speech ($p = .336$). Together these findings suggest that listeners' speech and song categorization was affected by musical acoustic characteristics in ambiguous utterances and that younger children (age 4 and age 6) were more willing to report these characteristics as sounding song-like than 8-year-olds and adults. Further, although ID

speech was greater than zero for all children, adults' responses were not different from 0% song responses. The proportion of song responses for ID speech was also very low for all ages, providing some of the first evidence that although ID speech and illusions may be described as more musical than adult-directed speech, it is not primarily perceived as song-like at any age in this task.

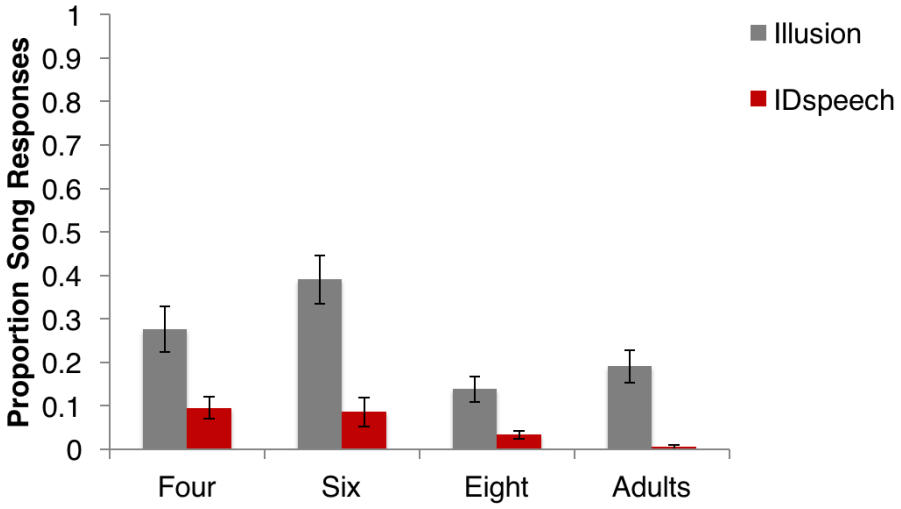

Figure 4. Proportion of song responses for ambiguous utterances shown for each age group.

To examine the possibility that listeners' use of acoustic features in this task changed over the course of development, we performed Multiple Linear Regression analyses using acoustic (Table 2) and emotional (Table 1) variables as predictors of song-like ratings, entered in a stepwise fashion separately for each age group. Because ratings of infant-directed stimuli were at floor with minimal variability (i.e. they all sounded like speech), this analysis only included stimuli from the overt sung, overt spoken, and illusion conditions. As average pitch is greatly affected by speaker gender, a dummy variable for gender was entered in the first step of the model to control for this factor. For all age groups, less F0 stability and longer average syllable duration predicted a significant amount of song responses (See Table 3). These factors explained 62.0% of the variance for adults, $F(3, 44) = 22.258$, $p < .001$, 61.2% of the variance for 8-year-

olds, $F(3, 44) = 21.56$, $p < .001$, 56.0% of the variance for 6-year-olds, $F(3, 44) = 17.417$, $p < .001$, and 52.6% of the variance for 4-year-olds, $F(3, 44) = 15.14$, $p < .001$. Thus, the same factors explained a significant proportion of the variance for all ages and none of the emotional factors were significant predictors of performance at any age.

Age Group	Predictor	Standardized Beta	t	Sig.
Four	Speaker Gender	-0.242	-2.215	$p = 0.032$
	F0 Stability	-0.644	-5.724	$p < .001$
	Syllable Duration	0.533	4.870	$p < .001$
Six	Speaker Gender	-0.259	-2.460	$p = .018$
	F0 Stability	-0.694	-6.403	$p < .001$
	Syllable Duration	0.522	4.773	$p < .001$
Eight	Speaker Gender	-0.402	-4.072	$p < .001$
	F0 Stability	-0.630	-6.193	$p < .001$
	Syllable Duration	0.602	5.862	$p < .001$
Adults	Speaker Gender	-0.355	-3.630	$p = .001$
	F0 Stability	-0.645	-6.401	$p < .001$
	Syllable Duration	0.625	6.153	$p < .001$

Table 3. Regression results for best fitting models shown for each age group. After controlling for speaker gender, all age groups relied on average F0 stability over the course of a syllable and average syllable duration.

Discussion

Experiment 1 provides the first evidence that children are able to categorize speech and song from age 4, even when several acoustic characteristics were carefully constrained. Further, listeners' categorization ability increased with age, reaching adult-like levels by age 8. Speech and song categorization appears to be particularly important for young listeners, as 4-year-olds with better speech and song categorization abilities also had higher vocabulary scores. The relation between verbal ability and speech and song categorization does not appear to be simply

related to general cognitive abilities as there was no relationship between categorization performance and matrix reasoning performance for this age group. Despite a strong relationship between categorization ability and vocabulary for 4-year-olds, there were no such relationships for other age groups. This may be related to the fact that listeners' categorization performance was increasingly near ceiling for older age groups, or because vocabulary was too coarse a measure of verbal ability. These limitations may not have allowed for a sufficient amount of variability necessary for relationships to become evident for older age groups. As such, the relationship between speech and song categorization and verbal ability should be carefully examined in future studies. In particular, using more fine-grained measures of speech processing and using a more sensitive measure of the recruitment of speech and song category knowledge could more directly address whether the presence of well-formed categories for speech and song actually leads listeners to weigh speech-relevant or song-relevant acoustic characteristics differently.

Although categorization ability increased with age, song categorization in particular got better with age. Thus, it appears that, although listeners were quite consistent in their categorization of spoken utterances, they were still learning to identify which features were diagnostic of song and speech when the acoustic characteristics were more constrained. This finding may also be related to the amount of time children hear song compared to speech in their daily lives. Although singing is prevalent in early childhood, parents sing more often to their children during the first two years of life (Custodero, Britto, & Brooks-Gunn, 2003). Thus, children may require a greater amount of experience with song in order to learn the features that are most predictive of song even though they are adept at identifying speech. However, younger children were also more affected by the musical acoustic characteristics of illusions when these

acoustic factors were unconstrained. It is possible that children still require multiple redundant cues to category membership, until they have more well-formed categories for speech and song as is the case in speech segmentation (e.g., Christiansen, Allen, Seidenberg, 1998). Thus, younger children may be more willing to rate the musical acoustic factors of ambiguous utterances as more musical due to their redundancy, even while they are still learning to tease apart acoustic characteristics that are more predictive of speech compared to song.

One surprising finding from the current study was that ID speech utterances were not rated as very song-like at any age. ID speech is a particularly interesting type of ambiguous utterance because there is a long history of describing these utterances as more musical (Fernald, 1989), due to their high pitch, repetition, and rhythmic regularity (Corbeil et al, 2013). However, the acoustic characteristics of ID speech (i.e., large pitch range and unstable F0) and participants' categorization responses were more consistent with overt speech than with overt song. Further, utterances with stable F0 over the course of a syllable and with longer syllable durations were more likely to be rated as song, but neither emotional valence or emotional intensity were significant predictors. One important difference between ID speech and other utterance types was that ID speech differed considerably in terms of the intended speaker. Thus, it is possible that the obvious direction of these utterances toward infants led listeners to discount the musical factors present within these utterance types. Yet, song was also rated as significantly more infant-directed than speech, but this did not appear to have an effect on adults' categorization performance. Future studies should examine the contribution of emotional valence and intensity when these factors are not correlated with the intended recipient of the utterance.

Even though participants of all ages relied heavily on these acoustic characteristics when forming categories for speech and song, the *use* of category information may not depend

primarily on acoustic factors. Therefore, Experiment 2 was designed to address how acoustic similarity and category membership contributed to auditory change detection in childhood.

Chapter 3: Experiment 2

Experiment 1 examined knowledge of sound categories directly by asking children to label auditory stimuli as speech or song. In Experiment 2, I examined the possibility that knowledge of sound categories indirectly influenced how children process complex scenes typical of everyday life. Although children have well-formed visual categories from their first year (Bornstein & Arterberry, 2010), category knowledge may not affect they way children listen to sounds in complex acoustic scenes. Change deafness, the auditory analogue to change blindness, is a fruitful way to observe what perceptual and cognitive factors contribute to the way that adults listen to the sounds around them (Snyder & Gregg, 2011). In a typical change deafness task, listeners are asked to detect changes between two dynamic acoustic scenes with multiple, simultaneously presented auditory objects (e.g., Gregg & Samuel, 2008). In adulthood, listeners rely heavily on basic-level semantic category knowledge (e.g., dog, train, bird) even more than the magnitude of an acoustic change to detect changes (Gregg & Samuel, 2009). There are no studies examining change deafness in childhood, which makes it unknown whether children would even exhibit change deafness or whether they would weigh category information as heavily as adults.

In the visual domain, there are a few studies examining visual change detection in childhood. In these studies, children attend to object-level information and semantically meaningful changes in complex visual scenes (i.e., central vs. marginal regions of interest) more than to changes involving only parts of objects (Shore et al., 2006; Fletcher-Watson et al., 2009). In contrast, the visual category induction literature indicates that younger children (age 4-5) rely primarily on visual similarity, whereas older children (11-12) rely solely on semantic category

labels (Sloutsky, Lo, & Fisher, 2001). Thus, it remains unclear whether children would weigh semantic category membership or acoustic features more heavily when they are detecting changes to everyday auditory objects in complex scenes.

Experiment 2 examined how existing category knowledge for several types of everyday sounds (i.e., animals, human vocalizations, musical instruments, and environmental sounds) affected change detection in 6-year-olds, 8-year-olds, 10-year-olds, and adults.[2] The main goals of Experiment 2 were to demonstrate whether children exhibited change deafness (Aim 1) and to examine whether children relied on acoustic similarity or category membership when detecting changes to everyday sounds in complex scenes (Aim 2). Further, I examined whether children of all ages could even encode and remember individual objects within each scene (Aim 3). In a standard change detection task all the sounds in a scene start at the same time. As common sound onsets and offsets are a primary means of auditory object formation (Shinn-Cunningham, 2008), it is possible that children will not be able to hear distinct auditory objects in each scene. Also, in order to apply category knowledge, the listener must be able to stream individual objects from other simultaneously presented objects. To examine this ability, I used an object-encoding task. In these tasks, the listener is asked whether or not a single sound was present in the previous change detection task (Gregg, Irsik, & Snyder, 2014). This task provides a measure of whether the listener was able to encode individual objects in each scene, as opposed to listening for any

[2] Six-year-olds were the youngest age group tested in previous auditory object processing literature and they were able to classify everyday sounds into categories during a free sorting task (Berland et al., 2014). In the developmental change blindness literature, there are typically three age groups with an average of 6, 8, and 10 years of age to capture the dynamic changes in working memory that occur during this age window (Gathercole et al., 2004). Further, a change detection task is taxing on auditory working and short-term memory and our task includes a secondary task which increases task difficulty. Given the attentional and dual task constraints, in addition to previous literature, I included school-aged children starting from age 6.

acoustic change without attention to individual objects. Similar tasks have been used in previous auditory (Gregg & Samuel, 2008; Gregg, Irsik, & Snyder, 2014) and visual change detection literature (Mitroff, Simons, & Levin, 2004).

Finally, the use of category information may be related to listeners' sophistication with language or to their general fluid intelligence. The final aim of this study was to relate change detection performance in general, and category use in particular, to standardized measures of vocabulary and fluid intelligence (Aim 4). In particular, the vocabulary subtest of the WASI measures children's vocabulary and general sophistication with language, which provides some insight into crystallized knowledge for everyday objects and concepts. Thus, this measure of vocabulary may be related to children's ability to use category knowledge in complex scenes. Of course, overall performance may be simply related to a listeners' general cognitive ability, as measured by performance on the matrix reasoning subtest, a test that examines participants' ability to determine part and whole relationships.

Given developmental findings from the change blindness literature, it was hypothesized that children would exhibit change deafness from as early as age 6 and that all listeners would be able to encode individual objects from complex change detection task scenes. Further, because of the similarity in task demands for change blindness and change deafness, it was hypothesized that all ages would rely primarily on semantic category knowledge compared to acoustic similarity. Finally, it was anticipated that vocabulary ability, as a measure of crystallized intelligence would correlate with listeners' reliance on category changes for all ages.

Method

Participants

Sixty-four 6-year-olds, 8-year-olds, 10-year-olds, and adults (16 for each age group) were recruited from the greater Las Vegas area or from the University's undergraduate psychology subject pool.[3] The average age was 6.6 years (sd: .23 years) for 6-year-olds (5 males), 8.4 years (sd: .29 years) for 8-year-olds (8 males), 10.4 years (sd: .27 years) for 10-year-olds (7 males), and 19.9 years (sd: .98 years) for adults (6 males). Ten additional 6-year-olds (average age: 6.3 years, sd: .25 years, 3 males) and three 8-year-olds (average age: 8.5 years, sd: .39 years, 1 male) were excluded from final analyses because they failed to understand the task, as indexed by a *d'* (hits = responding different on change trials, false alarms = responding different on same trials) of 0.3 or less. Three additional children were not included because they did not want to complete the task (two 6-year-olds, one 10-year-old). In the final sample, 12 6-year-olds (2 males, 6.7 years old on average), 11 8-year-olds (6 males, 8.7 years old on average), 13 10-year-olds (6 males, 10.4 years old on average), and 16 adults (6 males, 19.9 years old on average) completed the standardized tests of intelligence (see Procedure). Parents/caregivers provided consent for their child to participate and filled out demographic questionnaires on their child's behalf and children provided assent to participate. All parents reported that their child had normal hearing at the time of testing. Adults provided consent to participate and filled out demographic questionnaires. All adults reported normal hearing at the time of testing.

Apparatus

All participants were tested individually in the same manner as Experiment 1.

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[3] Power analyses indicated that 16 participants for each group was sufficient for a significant within-subjects effect for 4 conditions with a small effect size ($\eta_p^2 = .2$), which was anticipated due to the difficulty of the task and the attentional constraints of young participants.

Stimuli

To examine listeners' reliance on category knowledge and acoustic similarity, we created pairs of sounds that were within- or across-category changes and similar or dissimilar acoustic changes using 28 sounds (i.e., 14 unique categories with two exemplars for each sound category, see Appendix 2) for each condition. The majority of the sounds in the current study were taken with permission from Gregg and Samuel (2009). Two additional semantic sound categories (male and female, see Appendix 2) were also added in the same manner as the selection of stimuli in Gregg and Samuel (2008). All individual sounds were equated for total RMS amplitude, which is the best measure of dB SPL in a digital signal.

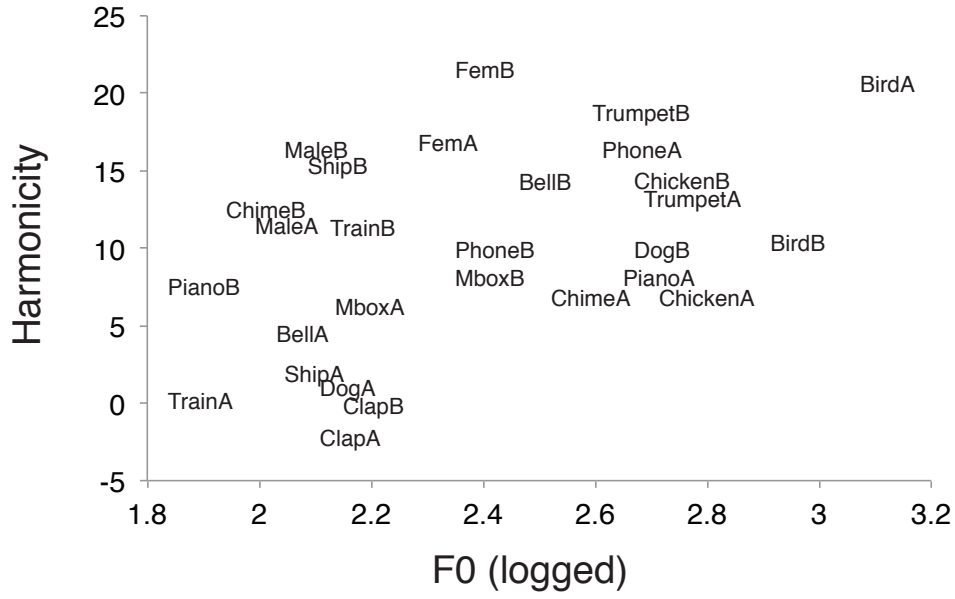

Figure 5. Two-dimensional space (harmonicity measured in dB and the log of mean F0 measured in Hz) used to calculate Euclidian distance for all the sounds used in the current experiment. Abbreviations: Fem = Female, Mbox = Music box.

Different trial pairings for the two acoustic similarity and category conditions relied on a given sound pair's Euclidian distance, which was based on a two-dimensional (2D) space created from each sound's mean F0 and harmonicity (degree of periodic information relative to noise in

the signal), after Gregg and Samuel (2009), as illustrated in Figure 5. F0 was calculated in the same manner described in Experiment 1. Euclidian distance was calculated using F0 and harmonicity because these dimensions are good measures of perceptual similarity for environmental sounds (Gygi et al., 2011; Gregg & Samuel, 2009).

For category change trials, the 2D acoustic space was used to create 14 across-category sound pairs that matched our 14 within-category sound pairs in terms of the Euclidian distance in order to control for the magnitude of the acoustic change during category change trials. For example, the distance between the within-category pair of "PhoneA" and "PhoneB" in Figure 5 was 6.39 units and the distance between its across-category counterpart "PhoneA" and "DogB" was 6.48 units (see Figure 5). The average Euclidian distance for all within-category different pairs was 6.55 units (SD = 3.77; range = 0.94 – 14.48) and the average distance for across-category pairs was 6.45 units (SD = 3.74; range = 0.95 – 14.74), yielding no significant difference between groups (p = .944). The other three sounds in each scene were chosen randomly using a custom MatLab script, with the exception that two exemplars from a single category (e.g., large dog bark and small dog bark) could not both be present in a single scene.

For acoustic similarity change trials, unique pairs were selected within a range of 0-4 Euclidian distance units to create 14 short-distance acoustic change trials. Similarly, we selected unique sound object pairs within a range of 8-13 units to create 14 acoustically dissimilar changes. For instance, in Figure 5 "PhoneA" to "TrainA" is an acoustically dissimilar change of 16.25 units and "PhoneA" to "FemaleA" is an acoustically similar change of 0.62 units. On average, Euclidian distance for acoustically similar trials was 1.29 units (SD = 1.0; range = 0.10 – 3.21) and for acoustically dissimilar trials it was 10.14 units (SD = 1.5; range = 8.12 – 12.50).

No within-category exemplars were used for any of the acoustic change trials, which means that all acoustic change trials were also across category changes.

Procedure

As with previous change deafness studies (Gregg & Samuel, 2008; 2009), we used the *one-shot paradigm* to examine children's ability to detect whether or not one auditory object changed from the first scene to the second scene. Both scenes were comprised of four concurrently presented environmental sounds and scenes were separated by a 350ms silent inter-scene interval. Same trials had identical sounds in both scenes, while different trials had one sound in scene 1 replaced by a new sound in scene 2 (i.e., the other three sounds remained the same in scene 1 and scene 2). As described above, different trials were from any of the four change conditions (across-category, within-category, dissimilar acoustic change, similar acoustic change). After hearing both scenes, participants indicated whether the scenes were the same or different by pressing a green key for "same" and a red key for "different." Overall, participants completed 84 change detection trials across two blocks, separated by a participant-controlled break. Fifty-six of the trials were change trials, with 14 trials for to each change type listed above. There were also 28 trials with no change (i.e., "same" trials), resulting in 33% same trials and 67% different trials.

After each change detection task, an object-encoding task began. Participants heard a single auditory object in isolation that was either *change-relevant* and unique to scene 1 (12 trials) or scene 2 (12 trials) or *change-irrelevant* and was presented in both scenes (16 trials) or neither scene (16 trials). For same trials, scene 1 and scene 2 were always identical, which only allowed for the assessment of objects from both scenes (14 trials) or neither scene (14 trials). Listeners were then asked whether or not they heard that single sound during the previous

change detection task. Participants used the green button to indicate that the sound was present in the previous change detection task ("Yes") or the red button to indicate that the sound was not part of the previous change detection task ("No"). A schematic example of a single trial is depicted in Figure 6.

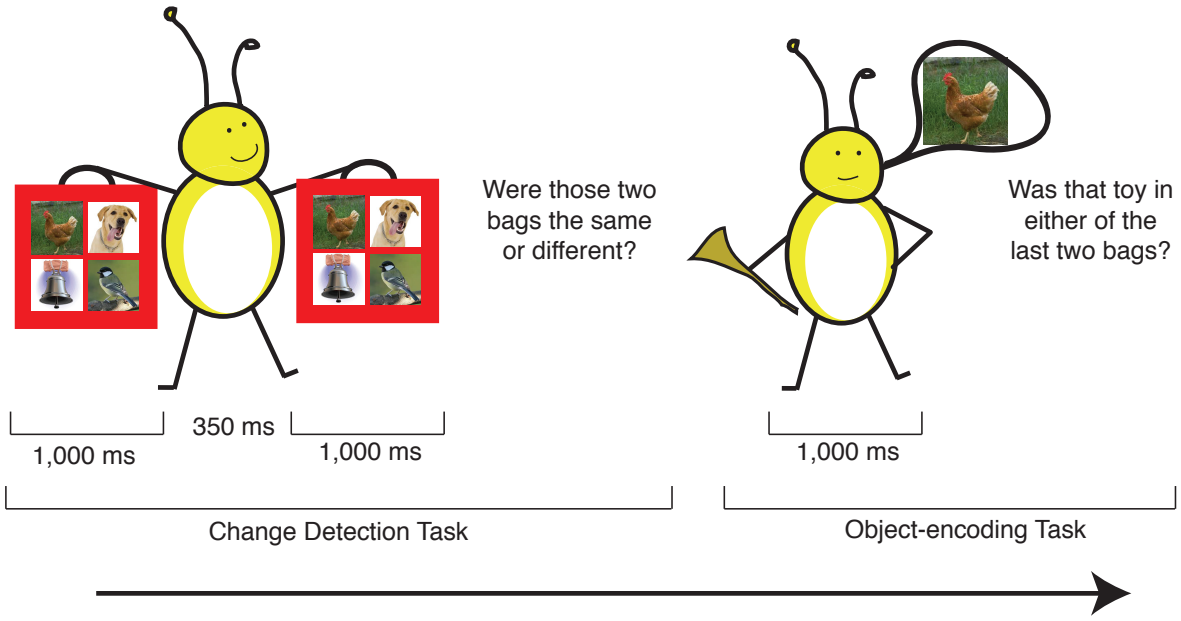

Figure 6. An example of a single "same" trial, which includes both the change detection task and the object-encoding task. During testing no pictures of sounds were present.

To make the task engaging for children, many of the techniques used to create exciting psychophysical tasks for young children were employed (Abramov et al., 1984). All participants were told a story about Bugsy (the yellow bug depicted in Figure 6) who was making party favor bags filled with toys that made sounds. Bags were the equivalent of a scene and the individual toys in the bags were the auditory objects. Participants were told that someone was changing the bags of toys and Bugsy needed someone to figure out which bags (scenes) were changed (different trials) and which bags were the same (same trials) so he could make all the bags the same for his party guests. Listeners completed two levels (i.e., two blocks) in order to get enough points to solve the mystery of the sound-changing bandit. All participants received non-

contingent feedback throughout the study. All participants were first familiarized with the testing paradigm during two rounds of training trials comprised of two- to four-object scenes accompanied by pictures. Following the computer game, participants provided responses for the Vocabulary and Matrix Reasoning subtests of the WASI. If children were not able to complete all tasks within the hour they were asked to return for a second visit to complete the WASI.

Results

Methodological considerations. Change deafness was operationally defined as more error on different than same trials, which is another way of measuring whether participants have a bias to respond "same" (Mitroff, Simons, & Levin, 2004). When error on same trials is low and uniform across conditions of interest, previous studies have simply used error on different trials as a direct index of what factors led participants to miss changes (i.e., error on different trials; Gregg & Samuel, 2009). However, because younger children are likely to have higher false alarm rates (as well as more misses) than older children and adults due to cognitive and attentional constraints, different trial error alone may be misleading as an index of change deafness. Previous studies have used *d*' from signal detection theory (Macmillan & Creelman, 1998) as a measure of the listeners' overall sensitivity to detect changes (Eramudugolla et al., 2005), but it is not a direct measure of change deafness because *d*' can differ solely as a result of false alarms, without any difference in how many changes are missed. We therefore used both approaches. We used error on same versus different trials to confirm the presence of change deafness, whereas we used *d*' as a measure of overall change detection sensitivity for comparison across conditions, except when false alarm rates could not be calculated.

Change detection analyses. To determine the presence of change deafness, error rates for same and different trials were compared across all age groups using a mixed-design ANOVA,

with trial type (same, different) as a within-subjects factor and age group (6, 8, 10, adult) as a between-subjects factor. A significant main effect of trial type, $F(1, 60) = 272.82$, $p < .001$, $\eta_p^2 = .82$, determined that there was a higher error rate on different than same trials, but trial type did not interact with age group ($p = .691$). There was a main effect of age group for overall error rates, $F(3, 60) = 15.56$, $p < .001$, $\eta_p^2 = .44$, indicating that error decreased for all trials (whether same or different) as age increased (see Figure 7). Planned comparisons showed that most ages were significantly different from each other (all p's < .014), except 8-year-olds were not different from 10-year-olds ($p = .616$) and 10-year-olds were not different from adults ($p = .562$), but there was no interaction between trial type and age ($p = .691$), suggesting that the rate of change deafness (i.e., greater error on different than same trials) did not differ with age. These results indicated that all listeners exhibited change deafness, with 34% error overall for different trials and 5% error on same trials, but change deafness did not decrease with age.

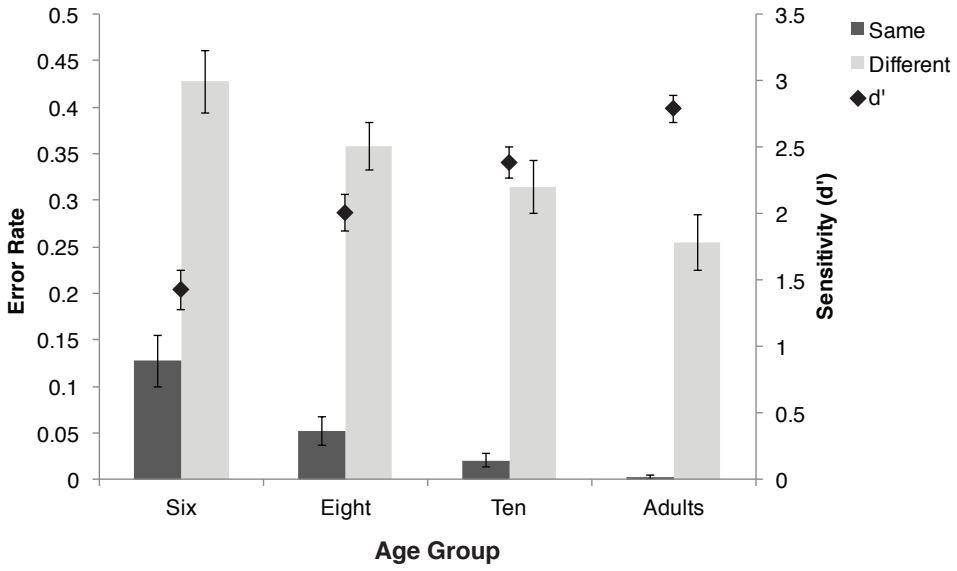

Figure 7. Proportion of error on same and different trials shows that all ages show evidence of change deafness (greater error on different than same trials), but rates of change deafness are stable for all ages. Overall sensitivity for detecting changes, measured in d', increased with age.

Because false alarm rates differed with age, participants' sensitivity (d') for detecting changes (Macmillan & Creelman, 1998) was calculated (hits = responding different on different trials; false alarms = different responses on same trials). The same overall decrease in error with age was confirmed using d', as indicated by a main effect of age group in a one-way ANOVA, $F(3, 60) = 20.48$, $p < .001$, $\eta_p^2 = .51$. Again, most ages were significantly different from each other (all p's < .013; see Figure 7), except that 8-year-olds and 10-year-olds ($p = .254$) and 10-year-olds and adults ($p = .171$) did not differ in sensitivity. Together these findings indicate that despite relatively stable rates of change deafness, change detection sensitivity increased with age, and reached adult-like levels of performance by age 10. This suggests that the factors underlying change deafness, such as limitations on auditory memory, attention, or the ability to segregate individual objects in complex scenes, are already present by age 6. Further, change sensitivity also increased with age, presumably due to fewer behavioral mistakes and better attentional control with age.

To determine whether semantic category and acoustic similarity affected change detection, d' was submitted to a mixed-design ANOVA with condition (across, within, dissimilar, similar) and age group. A main effect of condition was found, $F(3, 180) = 51.65$, $p < .001$, $\eta_p^2 = .46$, but it did not interact with age group ($p = .589$). Sensitivity for within-category changes was worse than all other conditions (see Figure 8), including the similar acoustic change condition ($p < .001$), which suggests that noticing a change between sounds with similar acoustic characteristics is less difficult than a change between sounds from the same semantic category. As predicted, sensitivity was worse for within-category (1.76) than across-category (2.32; $p < .001$) changes and sensitivity was worse for changes between acoustically similar (2.20) than dissimilar (2.31; $p = .017$) pairs of sounds. There was no difference between across-category and

dissimilar acoustic change conditions (p = .822), but listeners were more sensitive to across-category changes than similar acoustic changes (p = .034). A main effect of age group was also found, $F(3, 60) = 20.73$, $p < .001$, $\eta_p^2 = .51$, indicating that sensitivity increased with age. Six-year-olds were less sensitive than all other ages (p's < .012), adults were more sensitive than all other ages ($p < .001$) except 10-year-olds (p = .152), and 8-year-olds did not differ from 10-year-olds (p = .268).

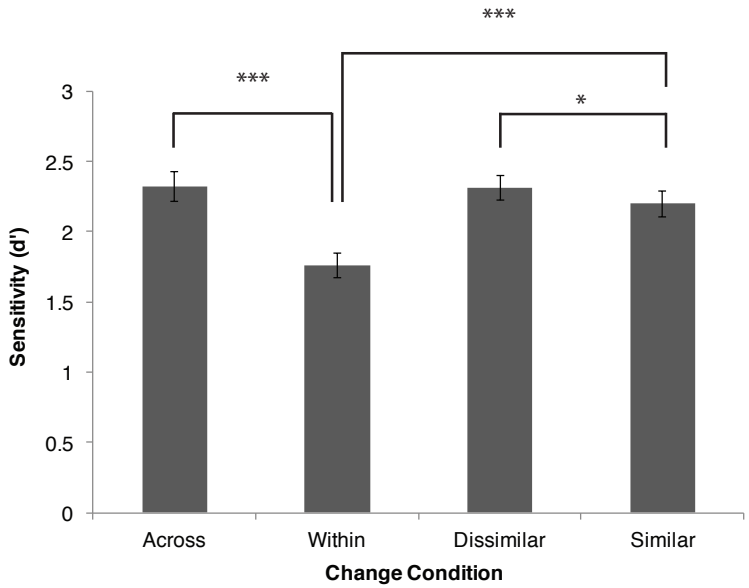

Figure 8. Sensitivity was worse for within-category compared to across-category changes and compared to acoustically similar changes, indicating that all ages relied more heavily on category knowledge than acoustic similarity.

Correlations were calculated between participants' vocabulary raw scores, matrix reasoning raw scores, overall sensitivity, the difference between across-category and within-category sensitivity, and the difference between acoustically dissimilar and similar change sensitivity for each age group separately. None of these correlations reached statistical significance (all r's < .168, p's > .2). Thus, change deafness did not relate to vocabulary or fluid intelligence outcomes. Further, these standardized measures were not related to the use of

semantic category knowledge or the magnitude of an acoustic change during the change detection task.

Object Encoding (OE) Analyses. For OE analyses, six children (three 6-year-olds and three 8-year-olds) were excluded because, despite understanding the change detection task, they did not understand the OE task. These six children pressed the "No" or red button for nearly every OE question, yielding nearly perfect performance on trials presenting an object that was in neither scene (0% error) and nearly floor performance (100% error) on all other trials.

To examine whether the remaining participants were able to encode individual objects presented in complex scenes, object-encoding sensitivity was submitted to a mixed-design ANOVA with OE type (change-relevant [scene 1, scene 2], change-irrelevant [both]) as a within-subjects factor and age group (6, 8, 10, adult) as a between-subjects factor. A main effect for OE type was observed, $F(1, 54) = 13.62$, $p < .001$, $\eta_p^2 = .20$, but the interaction between OE type and age was not significant, $F(3, 54) = 1.65$, $p = .189$, $\eta_p^2 = .08$. Thus, all age groups had worse sensitivity for change-relevant objects (1.34) than for change-irrelevant objects (1.50; see Figure 9b). In other words, an object presented in both scenes was more likely to be correctly identified than an object presented in only one scene. Age also impacted overall error rates, $F(3, 54) = 7.10$, $p < .001$, $\eta_p^2 = .28$, with an increase in sensitivity (i.e., better object encoding) with age. Planned comparisons found that 6-year-olds had worse sensitivity than adults (0.86 compared to 2.03; $p < .001$) and were marginally less sensitive than 10-year-olds (1.52; $p = .062$), although no other age comparisons were significantly different from each other (p's > .305) as illustrated in Figure 9a. Finally, all object-encoding performance was significantly above chance (6-year-olds: p's < .01; all other ages: p's < .001). These results suggest that children were able to form

coherent representations for individual objects even when sounds were presented with the same onsets as other sounds in a complex acoustic scene.

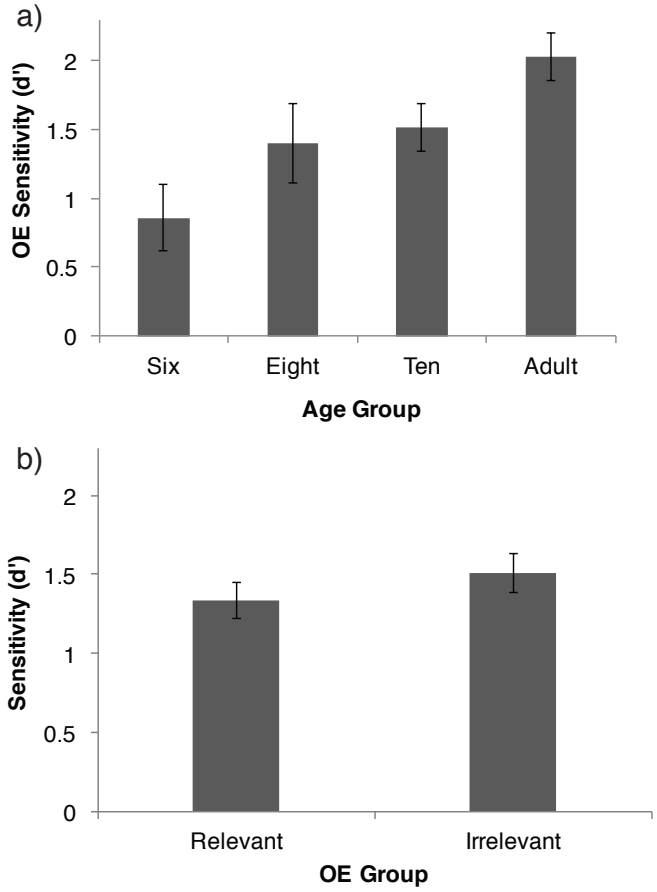

Figure 9. Object-encoding sensitivity a) increased with age and b) was worse for change-relevant objects compared to change-irrelevant objects.

Discussion

The current results provide the first evidence for the presence of change deafness in childhood. However, change deafness did not decrease with age, as the relationship between the amount of error on same compared to different trials was stable across all age groups. However, participants' overall sensitivity for detecting changes increased with age and approached adult-like levels by age 10. Sensitivity to change likely increases with age across modalities (see Fletcher-Watson et al., 2009; Shore et al., 2006) due to better control of attention and fewer

behavioral mistakes. These visual change detection studies did not include catch trials in which there was no change, however, which makes it possible that a change blindness paradigm that included no change trials would show a similarly stable change blindness effect even in the visual domain.

Already by age 6, children and adults use their category knowledge to listen for changes to real-world sounds in complex scenes. All participants were worse at detecting changes to sounds from the same basic-level category compared to sounds that changed from one category to another. Within-category changes were even harder to detect than small acoustic changes, which suggests that all listeners relied more heavily on semantic category knowledge than acoustic similarity to detect changes. Thus, these results are in line with previous change deafness studies in adulthood (Gregg & Samuel, 2009) and change blindness literature in childhood (Fletcher-Watson et al., 2009; Shore et al., 2006), which found that participants relied on their semantic knowledge of individual objects to detect changes in complex scenes. All listeners were also able to encode individual objects within busy acoustic scenes, which is important for the application of category knowledge. Although overall sensitivity for encoding sounds increased with age, all participants were better at encoding objects that were heard in both scenes (i.e., change-irrelevant) compared to sounds that were only heard in one scene (i.e., change-relevant).

It is important to note that although we did find a difference between acoustically similar and dissimilar changes, our effect was not as robust as previous studies with adults (Similar: ~2.2 d' units, Dissimilar: ~2.5 d' units; Gregg & Samuel, 2009). One possible reason for this difference is that after each change detection task, we included an object-encoding task that played each object in isolation. This additional exposure to each sound may have inadvertently

helped listeners better individuate each object during the change detection task, reducing the difficulty associated with segregating simultaneously presented objects in each scene regardless of the size of the acoustic change (cf. Shinn-Cunningham, 2008). It is also possible that when listeners heard each object alone, they adopted a more object-based strategy in our change-detection task. Thus, without the object-encoding task, it is possible that children and adults might have relied more equally on acoustic and semantic information. Further studies should examine change deafness without this object-encoding task to determine whether children are naturally biased toward using category knowledge or acoustic similarity, even though it is clear from the current study that they rely heavily on category knowledge.

Together, the results from object-encoding and change detection tasks suggest that listeners of all ages rely heavily on their category knowledge to detect changes in the sounds around them. Given that children are able to form visual categories already in their first year of life, it is perhaps not surprising that children in this study, who had a considerable amount of experience with everyday auditory objects, relied on category knowledge to detect changes to the sounds in acoustic scenes. Future work should examine the reliance on category knowledge and acoustic similarity in infancy, when children are initially learning about everyday sights and sounds.

Chapter 4: General Discussion

Together these experiments examined not only what factors listeners relied on to categorize multi-dimensional acoustic objects during development, but also whether category knowledge was used when listeners were performing a task that did not explicitly require listeners to categorize sounds. Categorization of speech and song was primarily based on listeners' attention to the acoustic characteristics that were diagnostic of the category instead of the functional role of emotional content in speech and song. Yet, when participants were listening for changes to everyday sounds in complex scenes, acoustic characteristics played less of a role than their knowledge of the sound's category. Thus, adults and children relied more heavily on acoustic characteristics to categorize auditory objects, but relied more heavily on their existing semantic category knowledge during a change detection task. Future studies should examine whether listeners can be biased to attend to the function of auditory objects during a categorization task or acoustic similarity during a change detection task in order to more fully address whether the results found here are indicative of processing biases or are task-specific.

To further understand how categorization ability is related to the application of category knowledge in everyday listening situations, it would be important to examination these factors at the same time with the same listeners. Specifically, it would be interesting to determine whether children who were better at categorizing everyday acoustic categories, like dogs, cars, and human voices, were also better at applying that knowledge in a change detection paradigm. Similarly, are children who are better at categorizing speech and song also better at applying speech- or song-specific knowledge? Such studies would help elucidate whether the underlying

mechanisms involved in categorizing sounds are also active when listeners are applying that knowledge in daily experiences or whether they are largely task-dependent.

Another important outcome of these studies is evidence that children can and do form categories for everyday objects that are multi-dimensional in nature. Previous studies on auditory categorization in development typically rely on a single dimension and are based in speech perception (e.g., Holt & Lotto, 2010). Further, there is a small literature on learning multi-dimensional acoustic categories in adulthood, but these studies rely on either artificial acoustic categories created in the lab (based on duration and frequency; Goudbeek, Swingley & Smits, 2009) or are again based on speech contrasts (pitch contour and phonetic content; Chandrasekaran, Yi, & Maddox, 2014). Thus, the current studies provide some of the first demonstrations of multi-dimensional acoustic category discrimination for everyday sounds during childhood and adulthood. Finally, it is also significant that children could apply category knowledge for individual objects even when they were presented under difficult listening conditions in complex scenes.

Together these studies have the potential to inform how typically developing children listen to the sounds around them by providing an understanding of what factors are important for category formation and category use under different task and contextual demands. This research is important for a wide range of listeners as forming categories for complex sounds, like speech and song, may be a crucial step for typical language development. Children with pervasive developmental disorders, like autism, have trouble using knowledge in a context- or domain-dependent manner, which is one of central deficits in several leading theories of autism spectrum disorder (Jarvinen-Pasley & Heaton, 2007; Happe & Frith, 2006). Deficits such as these have cascading effects on the way that listeners attend to important features in speech, like VOT,

while inhibiting irrelevant variations in pitch (Lepisto et al., 2008) or for attending to the human face over other visual objects in a scene (Kikuchi et al., 2009; Ro, Russell, & Lavie, 2001; New, Cosmides, & Tooby, 2007). The results presented here and future studies examining the perceptual and cognitive processes in categorization will help characterize how typically developing children weigh acoustic similarity and semantic category knowledge throughout the lifespan. Characterizing typical development is the first step toward assessing atypical development and designing clinical interventions for children that are developing atypically.

Appendices

Appendix 1: Sentences for Experiment 1

Training Stimuli

Song:

1. Mary had a little lamb
2. The Itsy Bitsy Spider
3. Amazing Grace

Speech:

1. Just hoist it up and take it away
2. The fruit of a fig tree is apple shaped
3. Our plans right now are hazy

Test Stimuli

Overt Song/Speech (same text)

1. Hop over the fence and jump in
2. Glue the sheet to the dark blue background
3. It's easy to tell the depth of the well
4. Yell and clap as the curtain slides back
5. Pour the stew from the pot into the plate
6. The wide road shimmered in the hot sun
7. Madam, this is the best brand of corn
8. The boy was there when the sun rose
9. Help the woman get back to her feet
10. Press the pants and sew the button on the vest
11. The wagon moved on well-oiled wheels
12. The paper box is full of thumb tacks
13. Both brothers wear the same size
14. A king ruled the state in the early days
15. When you hear the bell come quickly

Illusions

1. Here is no less
2. Gave the houses
3. Snags and sand bars
4. Somehow I can get
5. People in the neighborhood
6. And one cannot help wishing
7. Cannot guard yourself
8. I have had nothing since breakfast
9. You would know that you had heard it
10. Sudden commotion on the deck
11. For this was the only service
12. And the joy it would be
13. He restored the pretty things
14. The prince continued to struggle
15. Nothing but a scurvy faintness

Infant Directed Speech (ID speech)

1. Yeah, you're a pretty cool guy
2. Oh, nice stretch
3. Oh you almost grabbed it
4. Yeah, come on, bud, you almost got it
5. Yeah this is like your little gymnasium here
6. Yeah he's so flexible
7. Yeah it's interesting
8. We had a wonderful drive on the way here this morning
9. Good morning, how are you?
10. Hi, Alexander
11. We gonna go to the park today?
12. Boo-boo, you wanna go for a car ride?
13. It's nice and blue which is one of your favorite colors
14. What are we gonna do today?
15. Hello!

Appendix 2: Sounds for Experiment 2

Category	SoundA	SoundB
Human Voice		
Female	Speaking “ma”	Singing “la”
Male	Speaking “ma”	Singing “la”
Musical Instrument		
Bell	Large church bell	Small church bell
Music Box	Old time music box	Ballerina music box
Piano	Legato excerpt	Staccato excerpt
Trumpet	Staccato trumpet	Legato trumpet
Environmental		
Chimes	Ethereal chimes	Wind chimes
Clap	Quick claps	Slow claps in large room
Phone	Electronic ring	Old rotary dial phone ring
Ship	Barge ship horn	Low ship horn
Train	Train passing	Train whistle
Animal		
Bird	Songbird	Seagull
Chicken	Chicken cluck	Rooster call
Dog	Large dog bark	Smaller terrier bark

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2014 Center for Human Adaptive Systems and Environments (CHASE) Summer School attendee on the Dynamics of Music and Language (NSF-funded program at UC Merced)

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Refereed Journal Articles

Irsik, V.*, Vanden Bosch der Nederlanden, C.M.*, & Snyder, J.S. (Under Review). Broad attention to individual objects facilitates change detection in complex auditory scenes. ** indicates co-first authorship.*

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Hannon, E.E., Vanden Bosch der Nederlanden, C.M., & Matta, A. (In Preparation). Context-dependent influences on musical and linguistic rule-learning by adults.

Vanden Bosch der Nederlanden, C.M. (In Preparation). Just how specific is domain-specific processing in infancy? A review of music and language processing during the first year of life.

Vanden Bosch der Nederlanden, C.M., Hannon, E.E., Snyder, J.S. (In Preparation). Sorting speech and song throughout the lifespan.

Hannon, E.E., Vanden Bosch der Nederlanden, C.M., & Ullal-Gupta, S. (In Preparation). Classifying instrumental music by the language of origin during development.

Presentations

Vanden Bosch der Nederlanden, C.M., Hannon, E.E., Snyder, J.S. (2016, July). *Creatures of context: Recruiting musical or linguistic knowledge for spoken, sung, and ambiguous utterances.* Poster to be presented at the 24th International Conference for Music Perception and Cognition in San Francisco, CA.

Pabst, A., Vanden Bosch der Nederlanden, C.M., Washburn, A., Abney, D., Chiu, E. M., & Balasubramaniam, R. (2016, July). *Perceptual-Motor Entrainment in the Context of the Speech to Song Illusion: Examining Differences in Tapping Patterns to Perceived Speech vs. Song.* Poster to be presented at the 24th International Conference for Music Perception and Cognition in San Francisco, CA.

Vanden Bosch der Nederlanden, C.M., Snyder, J.S., Hannon, E.E. (2016, February). *Listeners can be biased to use object-level analysis during change detection.* Poster presented at the Mid-Winter Meeting of the Association for Research in Otolaryngology in San Diego, CA.

Vanden Bosch der Nederlanden, C.M., Snyder, J.S., Hannon, E.E. (2015, August). *Category knowledge can affect children's ability to detect changes in common sounds.* Paper and Poster presented at the Auditory Development: From Cochlea to Cognition Meeting at the University of Washington.

Vanden Bosch der Nederlanden, C.M., Hannon, E.E., Snyder, J.S. (2015, August). *The categorization of speech and song by adults.* Paper presented at the biennial meeting of the Society for Music Perception and Cognition in Nashville, TN.

Vanden Bosch der Nederlanden, C.M., Snyder, J.S., Hannon, E.E. (2015, August). *Children use semantic knowledge to detect changes in environmental sounds.* Poster presented at the biennial meeting of the Society for Music Perception and Cognition in Nashville, TN.

Vanden Bosch der Nederlanden C.M., Hannon, E.E., & Snyder, J.S. (2015, February). *Adult-like auditory object processing in children during change detection.* Poster presented at the Mid-Winter Meeting of the Association for Research in Otolaryngology in Baltimore, MD.

Vanden Bosch der Nederlanden, C.M., Hannon, E.E., & Snyder, J.S. (2015, January). *Categorizing speech and song in adulthood.* Poster presented at the Auditory Cognitive Neuroscience Society, in Tucson, AZ.

Hannon, E.E. & Vanden Bosch der Nederlanden, C.M. (2014, July). *Effects of music and language experience on auditory pattern learning during infancy and adulthood.* Poster presented at the Biennial International Conference on Infant Studies in Berlin, Germany.

Vanden Bosch der Nederlanden, C.M., Hannon, E.E., & Snyder, J.S. (2014, May). *Differences in the detection of pitch changes within a music and speech context.* Poster presented at the CHASE Summer School on the Dynamics of Music and Language in Merced, CA.

Vanden Bosch der Nederlanden, C.M., Snyder, J.S., & Hannon, E.E. (2014, March). *Examining the role of semantic knowledge on change deafness in early childhood.* Paper presented at the Graduate Research and Professional Student Association Research Forum in Las Vegas, NV.

Irsik, V.,* Vanden Bosch der Nederlanden, C.M.,* Gregg, M., & Snyder, J.S. (2014, February). *Effects of attention on change deafness depend on the task relevance of the attended object.* Paper presented at the annual meeting of the Association for Research in Otolaryngology in San Diego, CA. *Indicates co-presenters

Vanden Bosch der Nederlanden, C.M., Hannon, E.E., Snyder, J.S. (2013, August). *Differences in the detection of pitch changes within a music and speech context.* Poster presented at the biennial meeting of the Society for Music Perception and Cognition in Toronto, ON.

Vanden Bosch der Nederlanden, C.M., Hannon, E.E., Snyder, J.S. (2013, May). *The role of music-specific representations when processing speech.* Poster presented at the Inaugural Symposium on Music and Language Development at the Centre for Research on Brain, Language, & Music in Montreal, QC.

Vanden Bosch der Nederlanden, C.M., Hannon, E.E., Snyder, J.S. (2013, April). *Speech and music perception when listening to an auditory illusion.* Poster presented at the Graduate and Professional Student Association's Research Forum in Las Vegas, NV.

Vanden Bosch der Nederlanden, C.M. (2012, October). *Music and speech perception in adulthood: Using a musical illusion.* Paper presented for the Proseminar Fall Colloquium Series in Las Vegas, NV.

Hannon, E.E., Vanden Bosch der Nederlanden, C.M. (2012, July). *Music, language, and domain-specificity: Effects of native language on melodic pattern-learning.* Paper presented at the 12th International Conference on Music Perception and Cognition in Thessaloniki, Greece.

Vanden Bosch der Nederlanden, C.M. (2012, May). *Music and language pattern processing in infancy.* Short-paper presented as part of the Proseminar Spring Colloquium Series in Las Vegas, NV.

Campus Involvement & Service

2012 -present	Volunteer, Brain Awareness Week
2015	Panelist, Graduate Student Research Panel, UNLV Research Week
2015	Judge, Beal Bank USA Southern Nevada Regional Science & Engineering Fair
2014	Judge, UNLV Psi Chi Undergraduate Research Conference; Research Panelist
2012 - 2014	Developmental Emphasis & Cohort Representative, UNLV Experimental Student Committee (ESC)

Professional Memberships

Association for Psychological Science
Society for Music Perception and Cognition
Association for Research in Otolaryngology

Teaching Experience

2015	Guest Lecturer, Psychology 101: Human Memory (undergraduate lecture, UNLV)
2014	Guest Lecturer, Psychology 101: History of Psychology, Research Methods (undergraduate lecture, UNLV)
2012	Teaching Assistant, Sensation and Perception (undergraduate lecture, UNLV)
2011	Teaching Assistant, Human Development (undergraduate lecture, UNLV)

Reviewing

Ad Hoc – Journal of Experimental Child Psychology
Ad Hoc – Attention, Perception, & Psychophysics
Journal of Biomusical Engineering
Association for Psychological Science – Student Research Award