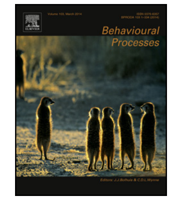
Behavioural Processes 123 (2016) 114–124

Contents lists available at ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc



Detection and discrimination of complex sounds by pigeons (*Columba livia*)

Robert G. Cook*,[1], Muhammad A.J. Qadri, Ryan Oliveira

Department of Psychology Tufts University, USA

ARTICLE INFO

Article history:
Received 5 August 2015
Received in revised form
19 November 2015
Accepted 19 November 2015
Available online 23 November 2015

Keywords:
Auditory perception
Auditory discrimination
Pigeons
Concept learning
Complex sounds

ABSTRACT

Auditory scene analysis is the process by which sounds are separated and identified from each other and from the background to make functional auditory objects. One challenge in making these psychological units is that complex sounds often continuously differ in composition over their duration. Here we examined the acoustic basis of complex sound processing in four pigeons by evaluating their performance in an ongoing same/different (S/D) task. This provided an opportunity to investigate avian auditory processing in a non-vocal learning, non-songbird. These pigeons were already successfully discriminating 18.5 s sequences of all different 1.5 s sounds (ABCD. . .) from sequences of one sound repeating (AAAA. . ., BBBB. . ., etc.) in a go/no-go procedure. The stimuli for these same/different sequences consisted of 504 tonal sounds (36 chromatic notes × 14 different instruments), 36 pure tones, and 72 complex sounds. Not all of these sounds were equally effective in supporting S/D discrimination. As identified by a stepwise regression modeling of ten acoustic properties, tonal and complex sounds with intermediate levels of acoustic content tended to support better discrimination. The results suggest that pigeons have the auditory and cognitive capabilities to recognize and group continuously changing sound elements into larger functional units that can serve to differentiate long sequences of same and different sounds.

1. Introduction

In humans, the study of the organization of complex sounds into larger units has received considerable attention, especially for the purposes of processing language and the appreciation of music. One rich vein in this area is auditory scene analysis, a set of psychological processes by which humans come to group and separate sounds from the background and from each other to form functional auditory streams and organized auditory “objects” in a “scene” (Bregman, 1994). Bregman proposed several Gestalt-like principles used by humans to parse apart and attend to auditory objects. These principles identify regularities in how humans group and segregate mixed and competing auditory frequency and amplitude information over time.

The complex sounds generated by human and non-human organisms regularly contain a broad range and distribution of frequency and energy information that varies over their durations. Consequently, non-human animals face the same perceptual problems as humans in identifying, grouping, and separating complex sounds in their normal environments. In most cases, however, the important ability to parse and recognize the differences and similarities of sounds, and then organize them into larger groups, is a poorly understood component of how animals process the continuous stream of auditory information in the natural world. A capacity similar to auditory scene analysis would seem especially valuable for birds, because they regularly use complex vocalizations for essential functions ranging from mate attraction to territorial defense (Gill, 1995; Hulse et al., 1997; MacDougall-Shackleton et al., 1998; Wisniewski and Hulse, 1997).

In the current article, we take advantage of a same/different (S/D) approach previously developed in our lab (Cook and Brooks, 2009) to investigate how pigeons process long sequences of changing auditory information. Using this task, we examined how different acoustic features in these stimuli contributed to their successful discrimination. Our understanding of visual S/D concept learning and processing in animals has made substantial progress over the last 20 years (Cook and Wasserman, 2006). Many of these advances can be attributed to the cutting edge research of Edward Wasserman and colleagues within this modality (Brooks and Wasserman, 2008; Castro et al., 2006; Cook and Wasserman, 2007; Gibson et al., 2006; Wasserman et al., 2001; Young and Wasserman, 2001a, 2001b; Young et al., 1997). Advancing our understanding of relational concept learning in animals is just one of his many contributions to the study of comparative cognition. As

* Corresponding author at: Department of Psychology Tufts University, 490 Boston Ave, Medford, MA 02155, USA.
E-mail address: Robert.Cook@tufts.edu (R.G. Cook).
[1] www.pigeon.psy.tufts.edu.

http://dx.doi.org/10.1016/j.beproc.2015.11.015
0376-6357/

confirmed by the contents of this special issue in his honor, there is no doubt that his impact has been substantial and widespread. Perhaps a good jumping off point for the current report comes from the notion that "all negative stimuli are not created equal" (Astley and Wasserman, 1992). While that statement specifically concerned the role of similarity within and across perceptual visual categories, we extend that observation here to include how different types of complex sounds also vary in their effectiveness in supporting auditory S/D discrimination.

Given our common interest in relational conceptual behavior using visual stimuli (Cook, 2002; Cook et al., 1995, 1997; Cook and Wasserman, 2006, 2007; Gibson et al., 2006; Wasserman et al., 2004), it was a natural to ask whether this type of abstract relational behavior extended to other modalities, like audition (Dooling et al., 1990). As a result, my laboratory began investigating how pigeons discriminate S/D sequences of auditory stimuli (Cook and Brooks, 2009; Murphy and Cook, 2008) as well as other types of auditory discriminations (Brooks and Cook, 2010; Hagmann and Cook, 2010). In the experiments most directly related to the current report, Cook and Brooks (2009) successfully trained pigeons in a go/no-go auditory S/D task in which the animals determined if a sequence of sounds was comprised of a series of different sounds or consisted of a single sound repeated over time. The pigeons were reinforced for pecking at S+ *different* sequences comprised of 12 randomly-selected sounds, while pecking at S- *same* sequences composed of one sound repeated 12 times resulted in a variable timeout. Cook and Brooks found that pigeons were able to learn the discrimination with tonal sounds and show generalized transfer to various novel stimuli (e.g., novel pitch/timbre combinations, pitches, instruments, and complex natural and man-made sounds). These results suggested that pigeons can learn generalized S/D concepts outside of their dominant visual modality. Using a different procedural approach, the relational nature of responding to auditory stimuli by pigeons, as well as control by their absolute properties, was also found by Murphy and Cook (2008). What was left unidentified in these studies, however, was the acoustic basis of this relational responding.

All acoustic stimuli are comprised of the summation of disturbances in the transmitting media, and they are frequently considered to be the summation of multiple sinusoidal functions. Pure tones are the simplest of all such stimuli. These consist of only a single sinusoidal wave that is described by a singular frequency and is perceived as a single pitch that does not change perceptually over time. Simple tonal sounds, such as those produced by musical instruments, are a little more complex than pure tones. Each of these contains a fundamental frequency that is the perceived pitch of the tone. Furthermore, there are additional harmonic frequencies that ebb and flow throughout the note duration which contribute to the timbre or distinctive sound of each instrument. These tonal sounds may also contain frequency and amplitude changes that cause variation in the perception of the attack or decay of the sound, as well as its possible vibrato. Computers can synthesize tonal sounds played by instruments by modeling the harmonics of the timbre at various frequencies and computing from those models the desired frequencies to generate a given instrumental sound. The top panel of Fig. 1 depicts a single note "played" by a computer-synthesized alto saxophone.

Next on the scale of harmonic intricacy would be various types of complex sounds, such as bird songs or man-made sounds. Complex stimuli are generally both harmonically and temporally more variable, especially since their content may change continuously over their duration. Two examples of such complex sounds are in Fig. 1, which shows the spectrograms of a man-made sound and a bird song. One of the challenges in the processing of these more extended complex sounds is to recognize the larger organization and structure of the sounds as they change with time. For instance, is the willet's song experienced as one large, two intermediate, or nine smaller units? Are the overlapping and simultaneous frequencies that start and stop asynchronously in the church bells perceived as a sequence of different tones starting and stopping at odd intervals or just one larger functional grouping?

Given this, consider for a moment a *same* trial in our S/D procedure when composed of a complex sound like the willet's song. In accordance with the training contingencies of our S/D task, the pigeons learn to suppress their pecking when presented with repetitions of a complex sound within a sequence. However, a complex stimulus has multiple frequencies and patterns that constantly change over every moment of its presentation. Thus, why do the pigeons not simply respond "different" to this ever-changing microstructure on *same* trials with complex stimuli? The answer must lie in part that the pigeons can recognize the repetition of the extended pattern of changing frequencies over time by grouping them together into larger representational units of a "sound." Because the momentary perception or statistics of complex sounds are inherently unreliable, the pigeons must be responding to the differences or the repetitions of such larger units when making auditory "same" or "different" responses.

Our ongoing program of auditory S/D research offered us an opportunity to examine this larger issue by evaluating how pigeons processed different complex stimuli and how they did so relative to simpler tonal stimuli. For example, because of their greater momentary differences, would complex sounds be more difficult to discriminate than simpler, more uniform tonal stimuli? Or, perhaps, would any perceptual differences among the sounds be equally sufficient, since all could fill the role of being "same" and "different" in the pigeons' generalized approach to the S/D task?

During the course of conducting other tests and experiments with our S/D experienced pigeons, we had collected an extended set of "baseline" data using a large number of tonal and complex stimuli that had been regularly presented over this period of time. As a consequence, we possessed a large database of S/D performance for each bird that we could draw on to see if and how there were differences among the auditory stimuli. Here, we report the analysis of S/D performance of four pigeons with a wide variety of tonal, natural, and artificial sounds. Further, we examined how a number of different acoustic properties correlated with their ability to recognize the repetition of these sounds. For the latter analyses, we concentrated on their responding on S- *same* trials. We did this because these S- trials have only a single, unambiguous stimulus that requires evaluation (as opposed to the multiple different sounds presented on each *different* trial), and they occurred with a higher frequency than usable positive trials (since S+ responding required evaluating non-reinforced trials that were programmed to occur less frequently).

Specifically, we evaluated how *same* trial performance with 504 tonal stimuli (14 musical instruments; 36 chromatic scale notes) and 72 complex sounds (26 bird sounds; 46 man-made and non-avian animal sounds) co-varied with ten different acoustic properties measured from each sound. These measurements included average frequency, average amplitude, and total silence-removed sound duration. Several metrics also captured the variation of the sounds over time as metrics of acoustic complexity. These included measures of the number of frequency and amplitude transitions, the overall ascending or descending nature of frequency and amplitude, and the average autocorrelation of the sound with itself. Our desire was to identify those properties leading to the best discrimination of "sameness" within these stimuli. Presumably, understanding how these acoustic properties influenced the relative perception of sameness would provide insight into how the pigeons also determine differences within a sequence.