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The use of prosodic cues in language discrimination tasks by rats

Received: 13 December 2002 / Revised: 24 March 2003 / Accepted: 31 March 2003 / Published online: 1 May 2003
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Abstract Recent research with cotton-top tamarin monkeys has revealed language discrimination abilities similar to those found in human infants, demonstrating that these perceptual abilities are not unique to humans but are also present in non-human primates. Specifically, tamarins could discriminate forward but not backward sentences of Dutch from Japanese, using both natural and synthesized utterances. The present study was designed as a conceptual replication of the work on tamarins. Results show that rats trained in a discrimination learning task readily discriminate forward, but not backward sentences of Dutch from Japanese; the results are particularly robust for synthetic utterances, a pattern that shows greater parallels with newborns than with tamarins. Our results extend the claims made in the research with tamarins that the capacity to discriminate languages from different rhythmic classes depends on general perceptual abilities that evolved at least as far back as the rodents.

Keywords Language discrimination · Prosody · Rats · Speech perception

Introduction

Several studies have shown that human newborns are able to distinguish between languages and that certain specific prosodic features, such as stress or rhythmic patterns, in spoken language are recognized and identified early in life (Mehler et al. 1988, 1996; Nazzi et al. 1998). Similarly, Moon et al. (1993) found that neonates show a preference for utterances in their mother tongue. It has been suggested that these capabilities might help newborns to

establish certain linguistic parameters, such as syntax, and hence serve as preconditions for linguistic development (Guasti et al. 2003). If so, from where do these early language discrimination capacities emanate? Are they unique to humans? Answers to such questions can help us to understand how and why speech is special.

One of the prosodic features that would appear to be most salient in spoken language that helps in language discrimination is rhythm. Initially, linguistic rhythm was associated with isochrony (Abercrombie 1967), and rhythmic classes were proposed. Stress-timed languages have isochronous stress intervals, whereas syllable-timed languages have isochronous syllables. More recently, Ramus et al. (1999) have proposed that rhythm correlates with the average proportion of vocalic intervals and the average standard deviations of consonantal intervals. Research with newborns has shown that early language discrimination abilities can be understood in terms of rhythmic class (see Mehler et al. 1996 for a theoretical framework). Work by Nazzi et al. (1998) indicated that infants could discriminate two rhythmic classes across at least two languages. These authors directly tested the linguistic rhythm hypothesis by comparing the performance of two groups of newborns, one habituated to sentences from two languages belonging to the same rhythmic class (English and Dutch, or Italian and Spanish), and the other habituated to sentences from two languages belonging to different rhythmic classes (English and Italian, or Dutch and Spanish). They reported an increase in sucking rates in newborns from the first group when tested with sentences from two languages of a different rhythmic class, whereas no increase in sucking rates was found in the second group (Nazzi et al. 1998).

To determine whether the capacity to discriminate languages based on their rhythmic class is unique to humans, Ramus et al. (2000) conducted habituation–discrimination experiments comparing the performance of human newborns and cotton-top tamarin monkeys in a language discrimination task. They used sentences from two languages belonging to different rhythmic classes (Dutch and Japanese). One of the experiments was run using natural sen-

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tences with variations across speakers. Another was run with synthesized sentences that eliminated that variation and preserved linguistic rhythm. A final experiment used the same synthesized sentences played backward, since it has been found that infants fail to discriminate between languages presented in that way (Mehler et al. 1988). More recently, it has been shown that different brain regions are activated in infants listening to forward and backward speech (Dehaene-Lambertz et al. 2002). Both human newborns and cotton-top tamarins discriminated the languages when the synthesized sentences were presented but not when they were played backward. In addition, cotton-top tamarins were able to discriminate across speaker variations in natural sentences, whereas human newborns did not. These results demonstrate that the ability to extract rhythmic information from the sentences of two languages is not exclusive to humans, and that neither human newborns nor cotton-top tamarins can pick up rhythmic cues from backward speech that can be used to discriminate between languages.

There have also been reported findings in the fields of categorical perception, the perceptual magnet effect, and amodal completion regarding the capacity of species such as quails, chinchillas, or cotton-top tamarins to organize their perception in ways that mimic that of humans for phonetic perception (i.e. Kuhl and Miller 1978; Kluender et al. 1987, 1998; Miller et al. 2001; Pons, unpublished data). Sentence discrimination on the basis of their rhythmic properties, and its failure with backward sentences, could also be a result of auditory processes present across other species given the results with tamarin monkeys.

The aim of the present study was first to explore to what extent there are general sensitivities across species in the use of prosodic cues, and second to determine if they are unique to the primate auditory system. To address this goal, a series of language discrimination experiments with rats was conducted. Given the difficulty of employing a habituation–dishabituation procedure with rats that could be similar to either spontaneous sucking rate in infants or spontaneous orienting response in tamarins, an alternative procedure based on lever-pressing training to measure rat responses was used. This is a fundamental difference between the present study and that of Ramus et al. (2000): in the present case training is required, but not in theirs.

General methods

Subjects

Subjects were 48 6-month-old adult Long–Evans rats, 26 males and 22 females. They were fed a fixed amount of food 1 h after each session. Each rat participated in only one experiment, and none had previous experience in lever-pressing experiments. Rats not meeting the criteria for lever pressing during training were dropped from the study (5 from experiment 1 and 1 from experiment 3). Thus, there were 11 rats in experiment 1, 16 in experiment 2, and 15 in experiment 3, for a total of 42 rats that were finally used.

Stimuli

The stimuli comprised 40 natural, 40 synthesized, and 40 synthesized and backward sentences in Dutch and Japanese. These sentences were the same as those used by Ramus et al. (2000). There were three different speakers of each language in the natural sentences. The synthesized sentences were created by Ramus et al. using software from the MBROLA project (Dutoit et al. 1996) so as to maintain a consistent set of prosodic features. Ramus et al. (2000) described the main features of the synthesized sentences as follows: “Phoneme duration and fundamental frequency were preserved, whereas the phonetic inventory was narrowed to only one phoneme per manner of articulation: all fricatives were synthesized as /s/, vowels as /a/, liquids as /l/, plosives as /t/, nasals as /n/, and glides as /j/” (p. 349). All sentences had a duration of around 3 s.

Apparatus

We used standard Leticia L830-C Skinner boxes connected to a PC computer. The computer was used to record the lever-press responses as well as to provide reinforcement. Sentences were played using a Pioneer A-445 stereo amplifier and two E.V. (S-40) speakers.

Experimental procedure

The same procedure was used in the three experiments. In experiment 1, rats were exposed to synthesized forward sentences, in experiment 2 to synthesized backward sentences, and in experiment 3 to natural forward sentences. For each experiment, rats were assigned to one of two groups. One group was trained to press a lever after Dutch sentences, and the other was trained to press a lever after Japanese sentences. There were 20 training sessions, 1 session a day. For each session, rats were taken from their home cage to the training cage, in which they were placed individually. Sessions involved the presentation of sentences for a 43-min period. Pilot studies had shown that rats were not able to maintain their response rates during sessions that were longer than 45 min. To keep sessions within this limit, the sentences from each language were randomly divided into two groups. Then, two series were created, each one containing 10 sentences from each language. Thus, each series comprised 20 sentences from the two languages that were presented in a balanced way in each session. The order in which series were presented across training days was balanced. After the presentation of each sentence there was a 2-min interval during which rats could respond. Following a sentence that was reinforced, rats received food throughout the 2 min on a VR-10 schedule. After a sentence that was not reinforced, rats did not receive food during the 1st minute of the 2-min interval, but only during the 2nd minute on a VR-10 schedule. This procedure helps to avoid extinction of the response in the non-reinforced trials.

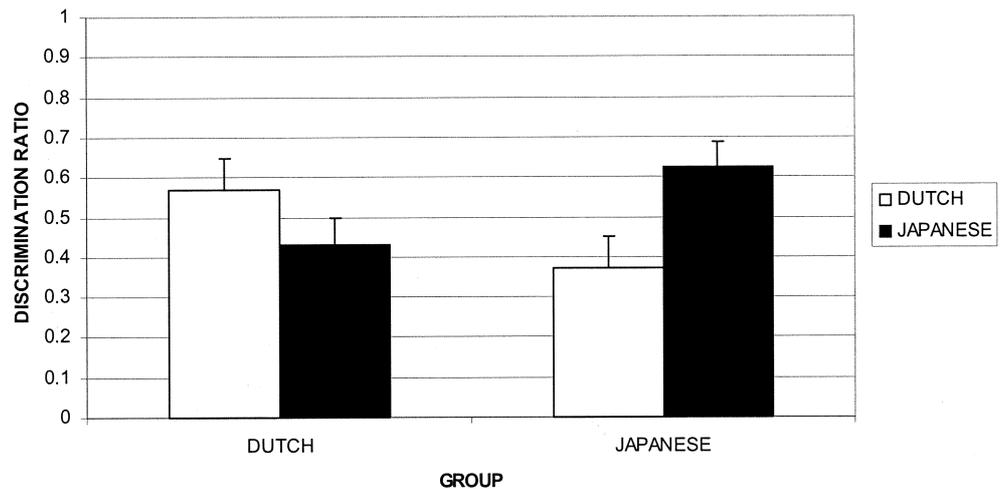
After the 20 training sessions, a test trial was run. This was similar to the training sessions and comprised 10 random sentences of each language out of the 20 that were used during training. So rats were tested on some of the same sentences they heard during training. However, food dispensers were disconnected, so rats did not obtain food after any sentence, regardless of whether they pressed the lever or not.

Experiments

Experiment 1

Experiment 1 was designed to determine whether rats could find common rhythmic features across 40 sentences and use them to discriminate between sentences of different lan-

Fig. 1 Test results for groups trained to lever press after synthesized Dutch or after synthesized Japanese sentences during experiment 1



guages. Twenty synthesized Dutch sentences and 20 synthesized Japanese sentences were used.

Results

Frequency of lever pressing during training sessions reflected an increase in its ratio after reinforced sentences. An analysis of variance (ANOVA) from the 20 days of training with group (Dutch or Japanese) as a between-subjects variable and days (1–20) and sentences (reinforced or non-reinforced) as within-subjects variables showed a significant effect of days ($F_{19,304}=7.333$, $P<0.001$), so behavior changed through sessions. The difference in responses to either reinforced or non-reinforced sentences during training was also significant ($F_{1,16}=6.369$, $P=0.0226$), whereas the behavior of both groups to Dutch and Japanese was not significantly different ($F_{1,16}=1.342$, $P=0.2636$). These results provide evidence of discrimination.

There is an alternative explanation for these results. It could be that rats kept on pressing the lever after reinforced sentences because food was obtained during the 1st minute of the interval, while refraining from doing so after non-reinforced sentences. To be certain that rats were actually discriminating sentences, they were not fed during test sessions. However, a pilot study showed a rapid extinction of response levels in the test sessions, which dropped to a minimum after 10 sentences, making differences disappear because of lack of responses. Therefore, only data from the first 10 sentences, 5 of each language, were analyzed. Results for the test session were calculated as a discrimination ratio.¹ Resulting mean values for Dutch group were 0.5697 (SD=0.078) for Dutch sentences and 0.4326 (SD=0.064) for Japanese sentences. As

¹The discrimination ratio was calculated by dividing the mean frequency of lever-pressing in the 1st minute (A) of the 2-min interval after each sentence by the mean responses in A plus mean responses in the 2nd min of this interval (C). This operation gives values between 1 and 0. Values tending to 1 indicate a higher mean response in A than in C; values tending to 0 indicate a higher mean response in C than in A (see Tarpay 2000; Toro et al. 2003).

for the Japanese group, mean values were 0.3708 (SD=0.082) for Dutch sentences and 0.6277 (SD=0.079) for Japanese sentences. An ANOVA with variable group (Dutch or Japanese) as a between-subjects variable and test language (Dutch or Japanese) as a within-subjects variable was performed. For variable group there were no significant effects ($F_{1,9}=0.011$, $P=0.9204$), whereas the interaction of group by test language was significant ($F_{1,9}=10.148$, $P=0.0111$). A simple effects test revealed that response differences between the two groups were significant for Dutch and Japanese sentences ($F_{1,9}=7.102$, $P=0.026$ for Dutch and $F_{1,9}=8.951$, $P=0.015$ for Japanese groups). Thus, rats could discriminate between Dutch and Japanese synthesized sentences (see Fig. 1).

Experiment 2

In this experiment we tested whether rats display a similar behavior pattern to that of infants and tamarin monkeys when the sentences are played backward. Infants and tamarin monkeys failed to pick out any feature in speech that could be used to discriminate between sentences when these were played in this way (Mehler et al. 1988; Ramus et al. 2000). Accordingly, the only difference between experiments 1 and 2 is that here the very same sentences were played backward.

Results

Training results showed a slight increase in mean frequency of lever pressing from day 1 to day 20. As in experiment 1, an ANOVA using the same variables revealed that the effect of days was significant ($F_{19,304}=3.102$, $P<0.001$), and the overall group effect was not ($F_{1,16}=3.763$, $P=0.0702$), indicating a change through sessions in both groups. But the difference in responses to reinforced and non-reinforced sentences was not significant ($F_{1,16}=1.554$, $P=0.2304$), suggesting a failure to learn the discrimination when the sentences were played backward.

Fig. 2 Test results for groups trained to press after synthesized backward Dutch or after synthesized backward Japanese sentences during experiment 2

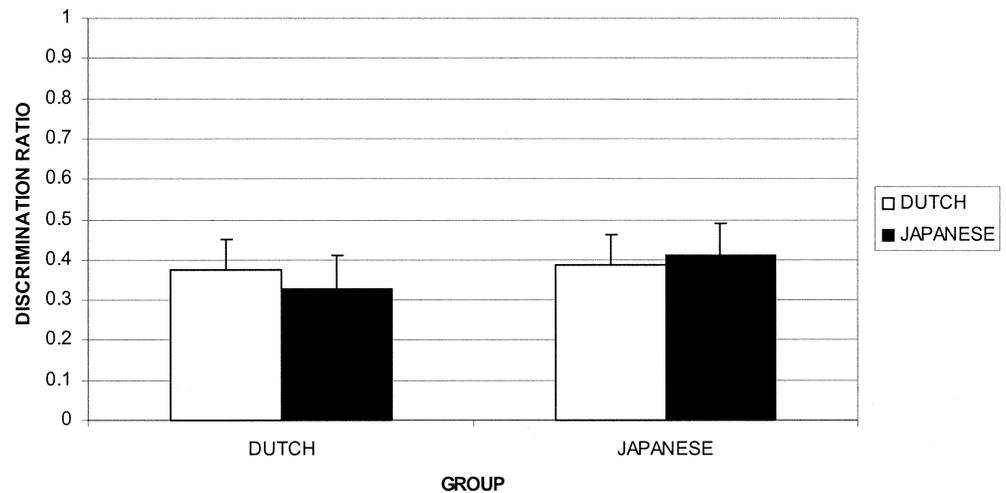


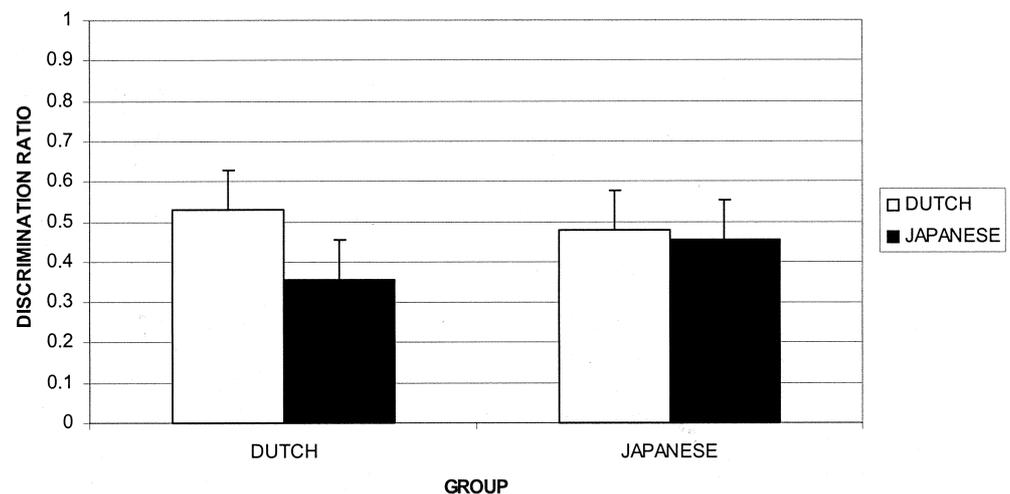
Figure 2 shows the results from the test session in experiment 2. In the test session, mean discrimination ratio values for the Dutch group were 0.3742 (SD=0.066) for Dutch sentences and 0.3293 (SD=0.074) for Japanese sentences. For the Japanese group, values were 0.3861 (SD=0.071) for Dutch sentences and 0.4097 (SD=0.092) for Japanese sentences. An ANOVA with variable group (Dutch or Japanese) as a between-subjects variable and test language (Dutch or Japanese) as a within-subjects variable showed that the interaction of group by language was not significant ($F_{1,14}=0.216$, $P=0.6491$). When the sentences were played backward, the rats were unable to extract any useful information so as to discriminate between sentences. These results were significantly different from those of the test session in experiment 1 ($F_{1,23}=7.182$, $P=0.0134$). Thus, it would seem that while rats were able to make effective use of the prosodic cues that are present in forward speech, they were unable to do so with backward speech.

Experiment 3

In experiments 1 and 2, rats showed a very similar response pattern to that of human newborns and tamarin monkeys

using synthesized sentences. However, Ramus et al. (2000) found that tamarin monkeys performed better than human newborns when the discrimination task involved natural sentences and implied a change of speaker. Surprisingly, human newborns did not discriminate between languages when there were various speakers per language, whereas tamarins displayed a discrimination pattern of responses. The authors suggested that this might be a consequence of tamarins being more sensitive to phonetic than to prosodic contrasts, since their performance was affected when only prosodic cues were available, as is the case with synthesized sentences. We wanted to test if this performance pattern generalized to rats; therefore, we conducted a further experiment using the same procedure as in the previous experiments, but using natural Dutch and Japanese sentences produced by three different speakers of each language. Sentences from the three speakers were presented in each series in a balanced manner during training and also in the test session to complete 20 sentences per session, and a total of 40 sentences for the two series.

Fig. 3 Results for groups trained to press after natural Dutch or after natural Japanese sentences during experiment 3



Results

For training sessions, an ANOVA revealed that the effect of days was significant ($F_{19,266}=8.028$, $P<0.001$), as was the difference in responses to sentences that were reinforced and sentences that were not ($F_{1,14}=6.851$, $P=0.0203$). Both groups showed a similar pattern of responses ($F_{1,14}=3.387$, $P=0.0870$).

Data from the test session revealed values of 0.5304 (SD=0.085) for Dutch sentences and 0.3543 (SD=0.078) for Japanese sentences in the Dutch group, whereas for the Japanese group, values were 0.4783 (SD=0.091) for Dutch sentences and 0.4540 (SD=0.089) for Japanese sentences. Analysis of variance showed no significant differences for variable group ($F_{1,13}=0.905$, $P=0.3589$). There was a group interaction by test language ($F_{1,13}=7.196$, $P=0.0188$). Simple effects tests showed that whereas the response difference between the two groups was significant for Japanese ($F_{1,13}=6.808$, $P=0.022$) it was not significant for Dutch ($F_{1,13}=2.064$, $P=0.174$), although results in the expected direction were observed (see Fig. 3). When results from experiment 3 were compared to those of experiment 1, it was observed that the variable experiment was not significant ($F_{1,22}=3.312$, $P=0.0824$), although differences between groups were more marked in experiment 1.

General discussion

The results from the present experiments show that with training, rats are able to discriminate between sentences of two languages that differ in their rhythmic properties when sentences are presented forward, but not when they are presented backward.

In experiment 1 rats were able to discriminate between the sentences of two different languages. To do so, rats had to extract the common features across the sentences of one language. These features are presumably prosodic, as a consequence of the stimuli used and as assumed by Ramus et al. (2000). Thus rats, like human newborns (Nazzi et al. 1998) and cotton-top tamarin monkeys (Ramus et al. 2000), display significant discrimination of sentences from two languages, one characterized as stress-timed (Dutch) and the other as mora-timed (Japanese).

Experiment 2 showed that rats could not extract information to discriminate one language from the other when the sentences were played backward. They were unable to perform adequately on the discrimination task with backward speech. This result is particularly significant because this same pattern was reported for human newborns (Mehler et al. 1988; Ramus et al. 2000) and cotton-top tamarins (Ramus et al. 2000), and therefore it may be characteristic of the auditory system of mammals. It has been proposed that in backward speech articulatory and phonetic cues that are sensitive to temporal order are distorted, while voice quality and frequency information is preserved (VanLancker et al. 1985). However, it is still not clear what is lost in backward speech that makes it unsuitable for language discrimination.

The results of experiment 3 were complex. Overall, rats could discriminate between the 40 Dutch and Japanese natural sentences. But when each group was separately inspected, only the Dutch group showed positive results. A priori, rats would not be expected to find it more difficult to solve the task with sentences from any particular language, and results from training sessions, and from experiment 1, point in this direction. It could be that particular speaker variability made it more difficult for rats to extract the common features across Japanese sentences, and so they could not differentiate them from Dutch sentences. This asymmetry in the results of language discrimination has also been reported in studies with human infants, when tested on English and French (Dehaene-Lambertz and Houston 1998). These authors suggested that this asymmetry could be reflecting some uncontrolled differences in the sentences of each language, making it more difficult to differentiate one language from the other. This explanation cannot be discarded in our experiment 3 and represents a potential difference with tamarins, where performance on natural speech utterances was, if anything, better than it was on synthesized utterances.

Our results extend the analysis of language discrimination abilities and may shed some light on the specialization of speech processing using a procedure that had not been used before to study these issues. Although direct comparisons between the present series of studies and previous research involving human newborns and tamarin monkeys have been made, it has to be remembered that the latter was based on a habituation–dishabituation procedure, whereas the present study involved training, since it was necessary in order to obtain a behavioral measure in rats. The fact that they failed to discriminate between backward sentences with this procedure, when tested with the same items they were trained to, makes a stronger case for a difference between forward and backward speech. Current experiments explore the extent to which rats can generalize to new sentences prosodic features extracted from speech, and the differences across species in the perceptual mechanisms involved in this process.

Taken together, the results from the present series of experiments suggest that language discrimination may rely on general perceptual abilities that are present at least across mammals. Furthermore, it seems that these abilities cannot be used effectively with backward speech. The question remains as to why rats display this discrimination pattern, and how it relates to other perceptual capacities that may be shared across species, and that we use in language (see Hauser et al. 2002). Nevertheless, much work is needed to set the limits for what kind of discriminations animals are able to do, and how they relate to specialized mechanisms responsible for what humans can accomplish in the field of speech perception.

Acknowledgements The research reported here was supported by a grant from the James S. McDonnell Foundation JSMF-20002079, the Catalan Government Research Grant SGR00034, and Fellowship AP2000-4164 from the Spanish MECED to the first author. The procedure was approved by the CEEA (Comité de Ética en Experimentación Animal) from the University of Barcelona and

complied with the guidelines of the Catalan and Spanish governments about treatment of laboratory animals. We are indebted to Dr. Frank Ramus and Dr. Marc Hauser for kindly supplying the stimuli used in this study. We would like to thank Dr. Laura Bosch and Dr. Albert Costa for comments on an earlier draft of this article.

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