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Nonhuman primates prefer slow tempos but dislike music overall

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Abstract

Human adults generally find fast tempos more arousing than slow tempos, with tempo frequently manipulated in music to alter tension and emotion. We used a previously published method (McDermott & Hauser, 2004, *Cognition*) to test cotton-top tamarins and common marmosets, two new-World primates, for their spontaneous responses to stimuli that varied systematically with respect to tempo. Across several experiments, we found that both tamarins and marmosets preferred slow tempos to fast. It is possible that the observed preferences were due to arousal, and that this effect is homologous to the human response to tempo. In other respects, however, these two monkey species showed striking differences compared to humans. Specifically, when presented with a choice between slow tempo musical stimuli, including lullabies, and silence, tamarins and marmosets preferred silence whereas humans, when similarly tested, preferred music. Thus despite the possibility of homologous mechanisms for tempo perception in human and nonhuman primates, there appear to be motivational ties to music that are uniquely human.

keywords: Music; Evolution; Monkeys; Tempo; Preference

Introduction

The origins of music are a long standing puzzle (Darwin, 1871). Empirical work in developmental (Trainor & Heinmiller, 1998; Trehub, 2003; Zentner & Kagan, 1996) and comparative (D'Amato, 1988; Hulse, Cynx, & Humpal, 1984; Izumi, 2000; Trainor & Heinmiller, 1998; Trehub, 2003; Watanabe & Nemoto, 1998; Watanabe & Sato, 1999; Wright, Rivera, Hulse, Shyan, & Neiworth, 2000; Zentner & Kagan, 1996) psychology can, however, constrain evolutionary theories by testing whether musically relevant traits observed among humans are innate and uniquely human (McDermott & Hauser, 2005). Traits that are innate and unique to humans are candidates for music-related adaptations; those that are shared by nonhuman animals are more likely to have evolved for other, domain-general functions.

To probe the uniqueness of our aesthetic response to music, we introduced a method for measuring spontaneous acoustic preferences in nonhuman animals (McDermott & Hauser, 2004); Watanabe and Nemoto (1998) had previously used a similar method to ask related questions in songbirds. We used this method to test cotton-top tamarins for several preferences that are pronounced and widespread in humans. The method revealed expected preferences in tamarins for soft over loud white noise, and for positive- over negatively-valenced conspecific vocalizations, suggesting its appropriateness as a measure of preference. When subsequently tested for other acoustic preferences found in humans, however, tamarins were indifferent. Specifically, tamarins failed to demonstrate a preference for consonant over dissonant musical intervals. In contrast, human adults showed the expected preference for consonance when measured with an analogous method. We concluded from these results that some of the essential preferences that underlie music perception in humans appear to be missing from some species of nonhuman primates, raising the possibility that such preferences are unique to our species.

In this paper we use the same method to probe nonhuman primate responses to tempo. Tempo, which we operationally define as the rate of acoustic events in a stimulus, is routinely manipulated in music to induce and resolve tension (Krumhansl, 1996) and to modulate affect (Hevner, 1937). Fast tempos are more arousing than slow, all other things being equal (Balch & Lewis, 1999; Husain, Thompson, & Schellenberg, 2002). So far as we know this is true across cultures, suggesting the effect of tempo may have an innate basis. Lullabies, for instance, tend to have slow tempos irrespective of their country of origin (Unyk, Trehub, Trainor, & Schellenberg, 1992), presumably in part because the slow tempo causes them to have a pacifying effect on their target listeners. This innate predisposition could be uniquely human, perhaps part of an adaptation for music. It is also possible that the predisposition is not specific to music, and could conceivably have been inherited from our nonhuman ancestors. To help distinguish these possibilities, we conducted experiments on cotton-top tamarins, as well as a close relative, the common marmoset.

1. General Methods

1.1 Apparatus and Procedure

The apparatus [a V-shaped maze, Fig. 1] and procedure were identical to that of McDermott and Hauser (2004). We placed concealed speakers (PolkAudio Atrium 45p) at the end of each branch of the maze; each speaker and branch was paired with a different sound. Subjects were initially placed at the entrance to the maze. The experimenter then left the room and raised the door to the maze by means of a pulley, allowing the animal to enter. We placed small pieces of food in both branches of the maze, equidistant from the entrance, to entice them to enter; the animals always ate both pieces of food. When the subject moved into a branch for the first time, the experimenter started the playback. The stimulus for a particular side played continuously as long as the animal was on that side, and switched as soon as it switched sides. The animal's position in the maze thus determined which sound it heard. Testing continued for 5 minutes. After a certain number of sessions with one sound on the left side and another on the right, generally separated by a full day, the sound-side pairing was reversed, and the animals were run for the same number of additional sessions. Data before and after the reversal were combined to distinguish stimulus preferences from side biases. The number of sessions for a single animal in a single experiment was usually 6 or 8. It was always fixed in advance of the experiment.

The computer program that turned the sounds on and off generated a list of the times at which one sound was started and the other was stopped. These times were almost identical to those extracted from video recordings of the sessions by blind observers ($r = .99$). The total time that a subject spent on each side was computed from these switch times. A statistically significant bias to spend more time in one branch than the other was taken as evidence for a preference for one sound over the other. Throughout, we test for statistical significance using two-tailed t-tests, with significance set at $p < 0.05$.

1.2 Method Validation

To validate the method, we first ran all participating animals in a control experiment using 60 and 90 dB white noise. If the method is appropriate for measuring preferences in our subjects, they should spend less time on the side playing loud white noise, which we presume to be relatively aversive. These experiments were described for the tamarin subjects in a previous publication (McDermott & Hauser, 2004); we repeated the same experiment in the six marmosets used in the present study. Marmosets averaged 63.3% (SE=1.58%) of the time on the soft side, which was statistically significant across the six animals ($t(41) = -7.62$, $p < 0.0001$), and for each animal individually (individuals spent between 56.5% and 68.8% on the side of the soft noise).

1.3 Participants

Both tamarin and marmoset subjects were born and raised in the lab, and had no exposure to music prior to our studies. We attempted to run as many animals as possible in each experiment, but due to issues of pregnancy, health and other lab constraints, this number varied somewhat from experiment to experiment. In a few experiments, the marmosets were unavailable to run. As it turned out, however, the marmosets and tamarins exhibited

similar results in every experiment in which they were both run. Every animal run in every experiment showed a significant preference for soft over loud noise, demonstrating the efficacy of the method in every subject we used. Care was taken to ensure that the total number of sessions was constant across experiments wherever possible.

1.4 Stimuli

Apart from the control experiments with white noise, the average intensity of each stimulus was always set at 62 dB. Pilot experiments at other stimulus levels suggested the specific amplitudes were not critical as long as they were matched across stimuli.

2. Experiment 1: Lullabies

We started with an extremely crude and coarse-grained contrast between two pieces of instrumental music: a Russian lullaby played on a flute, and an excerpt of German electronic techno. The two stimuli were intentionally chosen to be as different as possible, matching in average intensity while differing along almost every other dimension imaginable: spectral composition, attack rate, tempo etc. This large stimulus contrast was motivated primarily by our prior failure to find music-related preferences in tamarins (McDermott & Hauser, 2004). We wanted to see if any variables at all, apart from amplitude or behavioral relevance, might contribute to preferences in our nonhuman primate subjects. To rule out a possible role for differences in amplitude fluctuations for each stimulus, we filtered the techno excerpt to have the same amplitude envelope as the lullaby. To ensure that this amplitude modulation was not critical, we also ran a second experiment with the lullaby and the original techno excerpt as stimuli. To avoid any effects that human voices might have, we chose stimuli that were purely instrumental.

2.1 Method

In Experiment 1a we tested four adult cotton-top tamarins, 2 males and 2 females, as well as 4 common marmosets, 3 males and 1 female. In Experiment 1b we tested five adult cotton-top tamarins, one male in addition to the original 4; the marmosets were unavailable for this experiment.

The lullaby was a Russian folk song played on a flute. The techno was an excerpt from the track “Nobody Gets Out Alive” by Alec Empire (Digital Hardcore Recordings, 2000). In Experiment 1b, the techno was filtered so as to have the same amplitude envelope as the lullaby.

The number of total sessions (before and after the reversal) per subject was 8 for the tamarins in Experiment 1a, who were run first. As this effect was quite robust, we subsequently collected only 6 sessions per subject for the marmosets in Experiment 1a as well as for the tamarins in Experiment 1b. The number of sessions before and after the side reversal was always the same, as was the case in all the experiments.

2.2 Results and Discussion

Both tamarins and marmosets showed a robust preference for the lullaby over the techno (tamarins: $t(31)=4.47$, $p<0.0001$; marmosets: $t(23)=7.27$, $p<0.00001$; Fig. 2) in Experiment 1a. This preference was not an artifact of the amplitude modulation given to

the techno, as it persisted in Experiment 1b with the original techno excerpt and the same lullaby stimulus (the animals spent an average of 62.79% (SE=1.7%) on the lullaby side; $t(29)=6.45$, $p<0.00001$).

The two stimuli were equally loud to our ears, but it seemed conceivable that spectral differences between the stimuli might produce a loudness difference for the monkeys, whose loudness perception is not well characterized. We therefore ran a second control experiment with the tamarins, using 61 and 64 dB white noise stimuli. The difference in loudness produced by this 3 dB level difference is small but clearly perceptible to humans, and the experiment thus served as a test of whether small differences in loudness could account for our results. The tamarins showed no evidence of a preference for the lower amplitude noise ($t(31)=0.92$, $p=.36$; 8 sessions per animal for the four animals from Experiment 1a). Thus, it seems unlikely that a small loudness difference can account for the observed lullaby preference. Apparently some other difference between the two stimuli caused the monkeys to prefer one over the other.

3. Experiment 2: Click Trains

Any of the various differences between the stimuli of Experiment 1 could have conceivably caused the measured preference. One such difference was in the event rate, or tempo. We measured the average event rate of the lullaby and techno to be 65.26 and 369.23 beats per minute, respectively. To isolate the role of tempo, we used click trains, which were identical apart from the rate of repetition.

3.1 Method

We tested the 4 tamarins from Experiment 1a and 5 marmosets, four of whom were used in Experiment 1a. The clicks were impulses 0.12 ms in duration. In Experiment 2a, one stimulus contained 60 clicks per minute, evenly spaced, and the other 400 clicks per minute. These tempos were approximately matched to those of the stimuli of Experiment 1, and represent the approximate upper and lower limits of tempos found in music¹. To ensure that the results were not limited to such vast tempo differences, Experiment 2b presented click trains at 80 and 160 clicks per minute to 5 tamarins (including the four from Experiment 1). In both experiments each animal was run for 8 total sessions.

¹ It is rare to hear of tempos in music above 160 beats per minute, but this has more to do with limits on how fast humans move to music than with limits on how fast events occur in music. Humans typically entrain to rhythms at relatively slow rates, usually to metrical pulses that occur at some fraction of the event rate. This rate of metrical pulses is usually cited as the tempo even though the actual event rate of the piece in question might be considerably faster than that. It is common for the rate of events in a musical stimulus to range far upwards of 180 per minute, e.g. in drum rolls that often signal musical climaxes or in percussive dance music. It is this event rate that we are concerned with here rather than the rate of metrical pulses.

3.2 Results and Discussion

In Experiment 2a, both tamarins ($t(31)=3.54$, $p=.001$) and marmosets ($t(39)=3.33$, $p=.002$) preferred 60 clicks per minute to 400 clicks per minute (Fig. 3). This pattern of results was replicated with the smaller tempo difference (80 vs. 160 clicks per minute) of Experiment 2b ($t(39)=2.9212$, $p=.006$). When forced to choose, both species preferred stimuli in which events occurred at a slow rate. This provides a parsimonious explanation for the lullaby preference of Experiment 1.

4. Experiment 3: Attack Velocity

The stimuli presented in Experiment 1 also differed in the average attack velocity of the sounds composing the stimuli. The notes of the lullaby were gently blown and thus their onset was gradual; in contrast, the techno featured many brief percussive sounds, whose onset was rapid. It seemed possible that the rapid onsets were arousing to the animals and thus avoided. To investigate the role of the attack velocity we conducted an experiment in which this variable was isolated. We presented subjects with a choice between a pure tone with either a square wave or a triangle wave amplitude envelope; these stimuli differed maximally in their attack velocities but were equated for acoustic energy.

4.1 Method

We tested 2 marmosets and 4 tamarins out of the pool used in Experiment 1a, with 8 sessions per animal. The stimuli were produced by applying a 1 Hz envelope to an 800 Hz pure tone. The two envelopes used were a square wave and a triangle wave of the same amplitude, whose integrals were thus the same.

4.2 Results and Discussion

To improve power, we pooled the results across tamarins and marmosets; both as a group and individually they showed no preference between the two stimuli ($t(47)=.008$, $p=.994$; individuals spent between 47.9% and 52.4% on the side of the square wave envelope). Attack velocity, at least in the way that we manipulated it, thus does not appear to be responsible for the lullaby preference observed in Experiment 1.

5. Experiment 4: Music vs. Silence

Given that both tamarins and marmosets seem to prefer slow over fast tempos, one question of interest is whether they “like” slow tempo stimuli. One way to address this question behaviorally is by presenting subjects with a choice between various pleasant musical stimuli and silence. For purposes of comparison we tested human adults on this contrast, in addition to both species of monkey.

5.1 Method

We tested 8 human adults (18-21 years old, 6 female, 2 male), 4 cotton-top tamarins, and 5 common marmosets.

As described previously (McDermott & Hauser, 2004), human subjects were placed in a room divided in half by a stripe taped to the floor. There was a speaker on each side of the room; each speaker played a particular sound when the subject was in the corresponding half of the room. The human subjects were told only that they had to stay

within the confines of the room for the designated period of 5 minutes. After the experiment the human subjects were debriefed and were asked to rate how much they liked the stimulus on a scale of -3 (disliked) to 3 (liked).

For stimuli, we used the same lullaby as in Experiment 1, as well as a field recording of a lullaby sung in German (provided by Sandra Trehub), and a MIDI rendition of a Mozart string concerto (K458, in B flat major). After the first experiment with the flute lullaby (with 6 sessions per subject) yielded large effects, we ran the subsequent experiments with the sung lullaby and Mozart concerto with only 4 sessions per monkey subject, and with fewer subjects, as this provided adequate statistical power.

5.2 Results and Discussion

Human subjects consistently preferred the musical stimuli over silence as measured behaviorally (flute lullaby: $t(7)=2.67$, $p=.032$; sung lullaby: $t(7)=9.47$, $p<.0001$; Mozart concerto: $t(7)=3.36$, $p=.01$; Fig. 4). The ratings data were consistent with this behavioral effect, significantly greater than zero on average (flute lullaby: mean = 1.5, $t(7)=4.58$, $p=.0025$; sung lullaby: mean = 1.9, $t(7)=4.7$, $p=.002$; Mozart concerto: mean = 2.38, $t(7)=12.98$, $p<.00001$). In contrast, both tamarins and marmosets strongly and consistently preferred silence over the musical stimuli (flute lullaby - tamarins: $t(23)=-5.26$, $p<0.0001$; marmosets: $t(29)=-4.6$, $p<0.0001$; sung lullaby - tamarins: $t(11) = -3.93$, $p=0.003$, 3 animals; marmosets: $t(7) = -8.48$, $p= 0.0006$, 2 animals; Mozart concerto - tamarins: $t(15)=-5.33$; $p<.0001$, 4 animals; marmosets: $t(15)=-4.69$; $p=.0003$, 4 animals; Fig. 4). The monkey aversion to music was also evident if our analysis was restricted to data from the first session of each experiment, with animals spending more time with silence than with music in every case ($n=22$; the proportion of time spent on the music side ranged from 15.19% to 45.79%). Given this pattern of results, it seems unlikely that the monkeys find lullabies or other musical stimuli rewarding in the same way that people do.

6. Experiment 5: Energy Control

Given that the monkeys had relatively aversive responses to even the most pleasant of musical stimuli (at least as measured in our apparatus with a comparison to silence), several new issues emerged with respect to our tempo results in Experiments 1 and 2. For example, the fast click trains contained more acoustic energy per unit time than did the slow trains. The overall aversion to acoustic stimulation exhibited in Experiment 4 might, therefore, predict a preference for slow click trains over fast that could be unrelated to tempo. We therefore conducted an experiment with stimuli that varied in tempo but were equated in acoustic energy.

6.1 Method

We tested four cotton-top tamarins and one marmoset from Experiment 1a.

The stimuli were 800 Hz pure tones with a square wave envelope, as used in Experiment 3. The slow tempo stimulus had an envelope of 1Hz, producing 60 0.5 sec tone pulses per minute. The fast tempo stimulus had an envelope of 6.66 Hz, producing 400 0.075 sec tone pulses per minute. The stimuli thus had the same amount of acoustic energy per unit

time, while differing in their tempos, which again were approximately matched to the tempos of the stimuli of Experiment 1.

Each subject was run for 4 sessions with one stimulus assignment followed by 4 sessions of the reversed assignment.

6.2 Results and Discussion

All animals spent more time on the slow side (Fig. 5: ranging from 54.78% to 64.02%); this effect was significant for the tamarins as a group ($t(31)=3.54$, $p=.001$) and for the marmoset individually ($t(7) = 3.3$; $p=.01$). The preference for slow tempos over fast persisted even when stimuli were equated for acoustic energy.

7. Experiment 6: Chirp Trains

One question of interest is whether the tempo effect evident in tamarins and marmosets bears any relation to the effect of tempo on humans. Fast tempos are more arousing than slow tempos to humans, and although humans do not always prefer slower tempo stimuli, a similar difference in arousal could underlie the effect we found in our nonhuman primate subjects.

Another less interesting explanation, however, is again suggested by the results of Experiment 4. Although Experiment 5 ruled out an explanation of our tempo effects in terms of differences in total acoustic energy, if the individual sounds composing our stimuli are themselves unpleasant to the animals, then slow tempo stimuli might be preferred simply because they have fewer aversive acoustic events. The preference for slow tempos over fast could then be merely an indication that the animals do not like the onsets of the sounds we chose for stimuli. To control for this possibility, we sought to generate stimuli composed of non-aversive sounds, using elements of tamarin and marmoset vocalizations.

7.1 Method

We tested 6 tamarins and 3 marmosets, all of whom had previously demonstrated a preference for soft over loud noise. We were able to generate vocalization-based stimuli that produced non-aversive responses in 5 of the 6 tamarins and 1 of the 3 marmosets, thereby yielding 6 animals suitable for further testing. All of these animals, apart from one of the tamarins, had been tested in the previous experiment with click trains, and had shown a preference for the slower tempo.

We started with vocalizations that each species often produces in non-threatening situations. Tamarins often emit “chirps” when presented with food (Cleveland & Snowdon, 1981); presentation of food elicits chirp-like calls in marmosets as well. Tamarins also produce a “combination long call” that functions for long distance communication, and this vocalization begins with a brief chirp. We took recordings of these two kinds of chirps from various members of the tamarin and marmoset colonies, and created trains of them at various repetition rates. We then ran a series of pilot experiments (with 6 sessions total per subject) in which we presented subjects with a choice between slow tempo chirp trains (50 or 60 chirps per minute) and silence,

searching for stimuli that our subjects would at least prefer equally to silence. The monkeys for whom such stimuli were found were then run on an experiment with fast tempo chirp trains (250 per minute) vs. silence, and then again on slow chirp trains (50 per minute) vs. silence, counterbalanced for order, again with 6 sessions per subject. The higher chirp rate of 250 per minute was chosen to approximately match the fastest rates that we observed naturally in the animals. For both tests we recorded the number of times the animals switched from left to right in our apparatus, as it seemed that this measure of activity might be informative with respect to their arousal level.

The non-aversive slow chirp trains were composed of either the chirps from a cagemate's combination long calls ($n=3$ tamarins), the cagemate's food chirps ($n = 1$ marmoset), or the food chirps from an unrelated, long deceased tamarin ($n = 2$ tamarins). These six animals were then tested on fast and slow chirp trains composed of these chirps (the slow chirp trains were repeated to avoid selection bias and order effects). One of the six animals was not run on the full series of tests and her data are omitted from the group analysis. The data from the other 5 animals are combined.

7.2 Results and Discussion

None of the animals spent significantly different amounts of time with their customized slow chirp trains (50 or 60 chirps/min, depending on the animal) compared to silence, individually or as a group ($t(29)=-0.18$, $p=.85$). However, when the same chirps were presented at a faster rate of 250 per minute, the same animals consistently preferred silence over the chirps ($t(29)=-5.99$, $p<0.00001$; Fig. 6). When tested again on slow chirp trains composed of the same chirps, the same animals again spent equal amounts of time with the chirps as with silence ($t(29)=-0.77$, $p=.45$; Fig. 6). This effect is not well-accounted for via the cumulative effect of aversive sounds, as the chirps are non-aversive when played at slow rates. It also seems unlikely that the effect is due to the fast trains being less ecologically valid, as we have frequently observed the animals make rapid bursts of chirps at rates close to our fast presentation rate. Rather, it appears that both tamarins and marmosets find fast tempos aversive. We also observed a significant difference in the average number of times the animals moved from one side of the apparatus to the other – they averaged 21.86 side switches per session ($SE=2.22$) during the fast tempo sessions, and 27.56 ($SE=2.17$) for the slow tempo sessions ($t(70)=1.84$, $p=.03$). This is consistent with the hypothesis that the fast tempo stimuli are aversive, and that the animals are less likely to revisit the side with the aversive stimuli once they have been there.

8. Conclusions

In previous work we reported evidence that nonhuman primate spontaneous acoustic preferences differ dramatically from those of humans (McDermott & Hauser, 2004), and the experiments described in the present paper largely support this idea. Where humans choose to hear music over silence, monkeys choose the reverse, suggesting that they do not find such stimuli pleasurable or relaxing. However, despite the apparently aversive response monkeys have to many musical stimuli, we found for the first time evidence that they do have nontrivial preferences for some musical stimuli over others, and our results suggest that tempo is a critical variable.

Is the monkey response to tempo homologous to the human response to tempo? Further work is needed on this topic, but our results at least leave this possibility open. Humans obviously do not always prefer slow tempos to fast, but differences in temperament could cause tamarins and marmosets to find arousing stimuli aversive, whereas to humans they would merely be stimulating. Many stressful events in the natural environment, such as fights and storms, feature rapid sequences of acoustic events, and it is thus conceivable that animals have come to associate such stimuli with high levels of arousal. Future work using direct measures of arousal could provide further support for this hypothesis. It is also interesting to note that the alarm calls of tamarins and marmosets consist of short broadband bursts repeated at very high rates (Fig. 7 shows one such call from a tamarin). This acoustic structure is common to certain types of alarm calls in species ranging from monkeys and squirrels to birds (Marler, 1955), and could be related to the response nonhuman animals have to fast-tempo stimuli. Taken as a whole, however, the body of work on music perception in nonhuman primates suggests fundamental differences in the way they respond to musical stimuli compared to humans. Our preferences for certain kinds of music may reflect a unique evolutionary history of selection on perceptual mechanisms linked up with our emotional and motivational systems.

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References

- Balch, W. R., & Lewis, B. S. (1999). Music-dependent memory: The role of tempo changes and mood mediation. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 22, 1354-1363.
- Cleveland, J., & Snowdon, C. T. (1981). The complex vocal repertoire of the adult cotton-top tamarin, *Saguinus oedipus oedipus*. *Zeitschrift fur Tierpsychologie*, 58, 231-270.
- D'Amato, M. R. (1988). A search for tonal pattern perception in cebus monkeys: Why monkeys can't hum a tune. *Music Perception*, 5(4), 453-480.
- Darwin, C. (1871). *The descent of man and selection in relation to sex*. London: John Murray.
- Hevner, K. (1937). The affective value of pitch and tempo in music. *American Journal of Psychology*, 49, 621-630.
- Hulse, S. H., Cynx, J., & Humpal, J. (1984). Absolute and relative pitch discrimination in serial pitch perception by birds. *Journal of Experimental Psychology: General*, 113(1), 38-54.
- Husain, G., Thompson, W. F., & Schellenberg, E. G. (2002). Effects of musical tempo and mode on arousal, mood, and spatial abilities: Re-examination of the "Mozart effect". *Music Perception*, 20, 151-171.
- Izumi, A. (2000). Japanese monkeys perceive sensory consonance of chords. *Journal of the Acoustical Society of America*, 108(6), 3073-3078.
- Krumhansl, C. L. (1996). A perceptual analysis of Mozart's piano sonata K. 282: Segmentation, tension and musical ideas. *Music Perception*, 13(3), 401-432.
- Marler, P. (1955). Characteristics of some animal calls. *Nature*, 176, 6-7.
- McDermott, J., & Hauser, M. (2004). Are consonant intervals music to their ears? Spontaneous acoustic preferences in a nonhuman primate. *Cognition*, 94(2), B11-B21.
- McDermott, J., & Hauser, M. D. (2005). The origins of music: Innateness, uniqueness, and evolution. *Music Perception*, 23(1), 29-59.
- Trainor, L. J., & Heinmiller, B. M. (1998). The development of evaluative responses to music: Infants prefer to listen to consonance over dissonance. *Infant Behavior and Development*, 21(1), 77-88.
- Trehub, S. E. (2003). The developmental origins of musicality. *Nature Neuroscience*, 6(7), 669-673.
- Unyk, A. M., Trehub, S. E., Trainor, L. J., & Schellenberg, E. (1992). Lullabies and simplicity: A cross-cultural perspective. *Psychology of Music*, 20(1), 15-28.
- Watanabe, S., & Nemoto, M. (1998). Reinforcing property of music in Java sparrows (*Padda oryzivora*). *Behavioural Processes*, 43(2), 211-218.
- Watanabe, S., & Sato, K. (1999). Discriminative stimulus properties of music in Java sparrows. *Behavioural Processes*, 47(1), 53-57.
- Wright, A. A., Rivera, J. J., Hulse, S. H., Shyan, M., & Neiworth, J. J. (2000). Music perception and octave generalization in rhesus monkeys. *Journal of Experimental Psychology: General*, 129(3), 291-307.
- Zentner, M. R., & Kagan, J. (1996). Perception of music by infants. *Nature*, 383(6595), 29.



Fig. 1. Photo of the apparatus used in the tamarin and marmoset experiments.

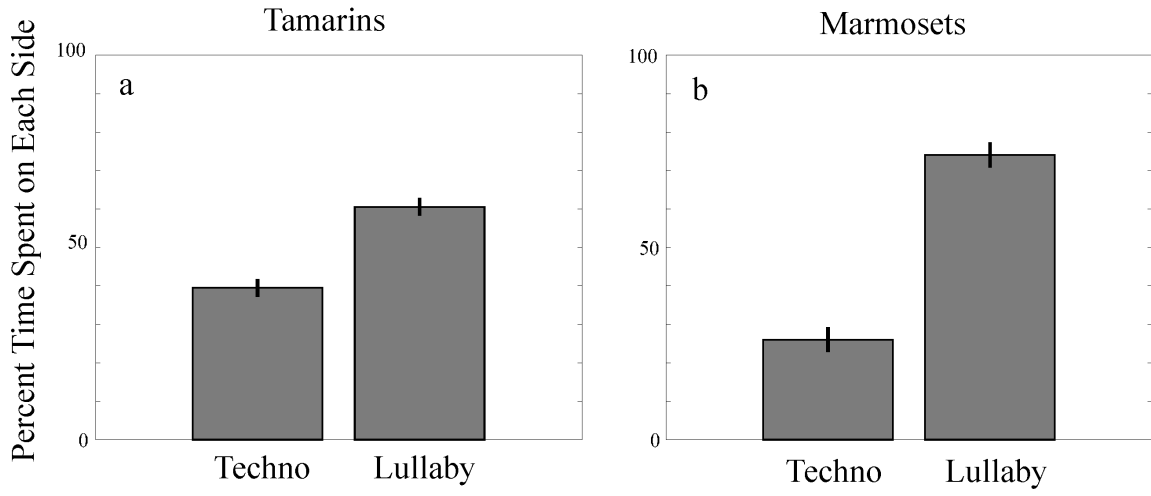


Fig. 2. Results of Experiment 1a, comparing a lullaby played on a flute with electronic “techno” filtered to have the same amplitude envelope. The bars plot the average data from the tamarins and marmosets run in the experiment. Error bars here and elsewhere denote standard errors. (a) Results for tamarin subjects. (b) Results for marmoset subjects.

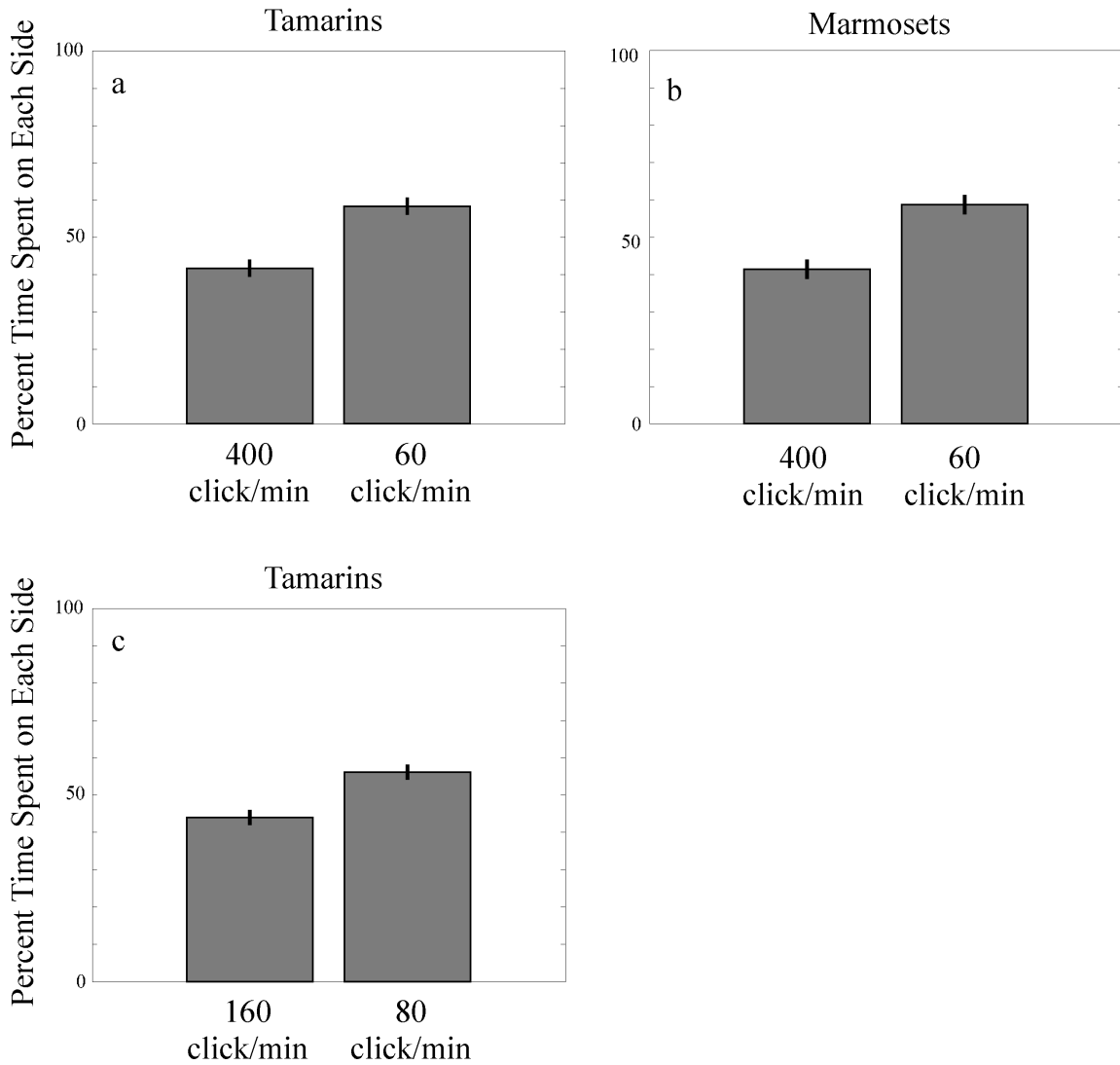


Fig. 3. Results of Experiment 2, comparing slow and fast click trains. (a) Results for tamarin subjects, 60 vs. 400 clicks per minute. (b) Results for marmoset subjects, 60 vs. 400 clicks per minute. (c) Results for tamarin subjects, 80 vs. 160 clicks per minute.

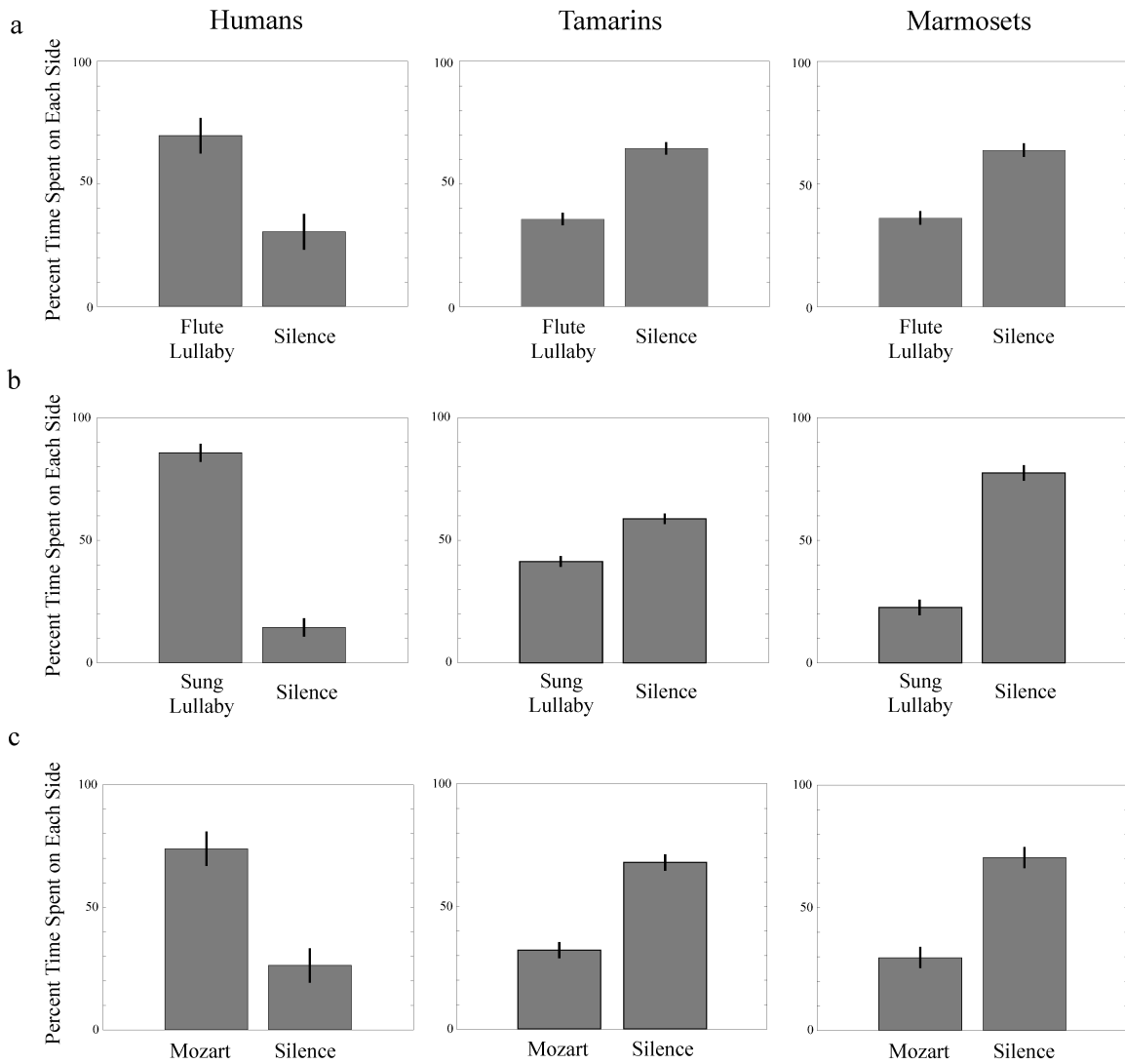


Fig. 4. Results of Experiment 4, comparing various musical stimuli to silence for human, tamarin and marmoset subjects. (a) Results for an instrumental lullaby played on a flute. (b) Results for a lullaby sung in German. (c) Results for a Mozart string concerto.

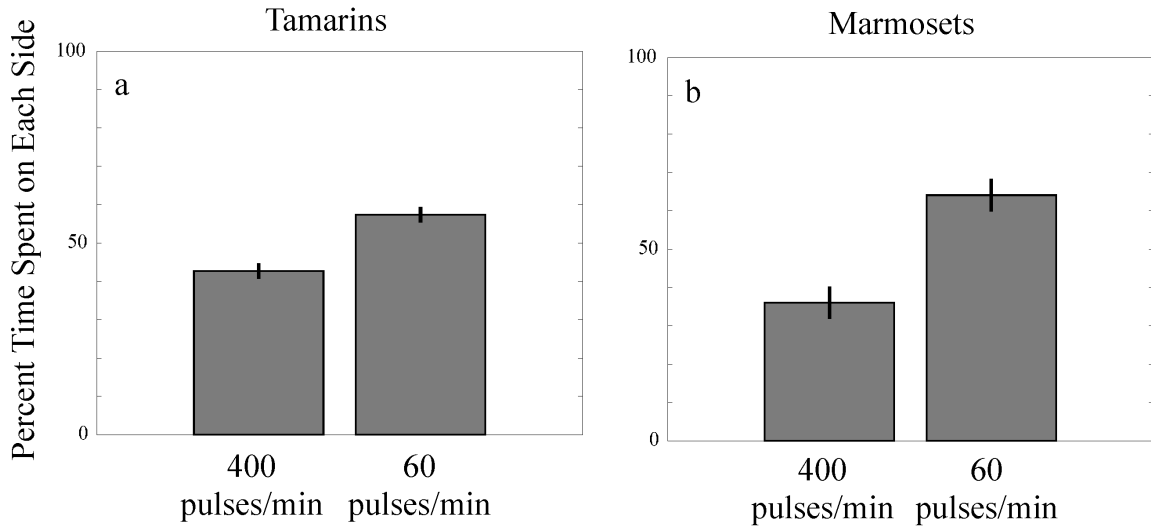


Fig. 5. Results of Experiment 5, comparing fast and slow tempo stimuli equated for acoustic energy. (a) Results for tamarins. (b) Results for a single marmoset subject.

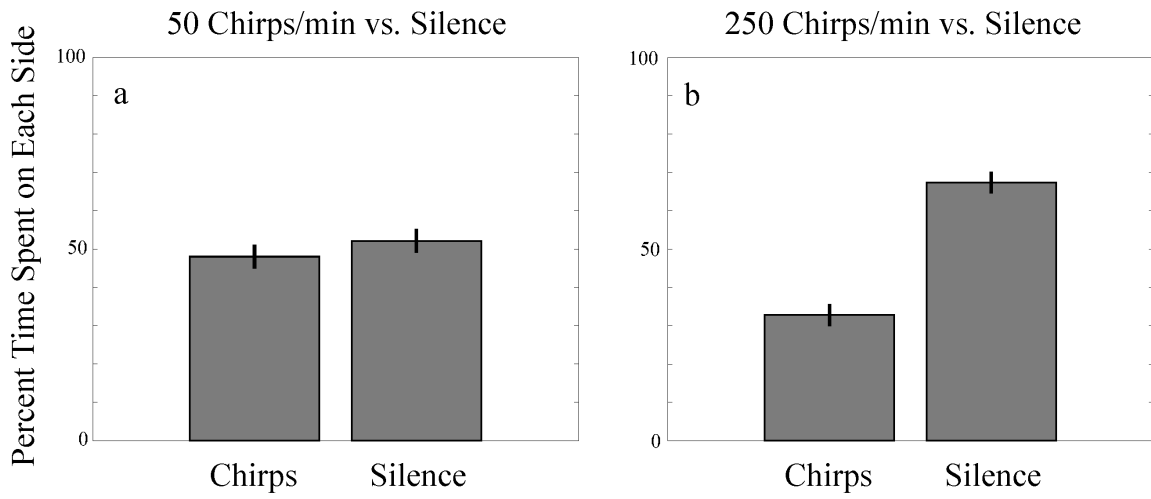


Fig. 6. Results of Experiment 6, comparing slow and fast chirp trains to silence, for 4 tamarins and 1 marmoset. (a) Results for slow chirp trains vs. silence. (b) Results for fast chirp trains vs. silence.

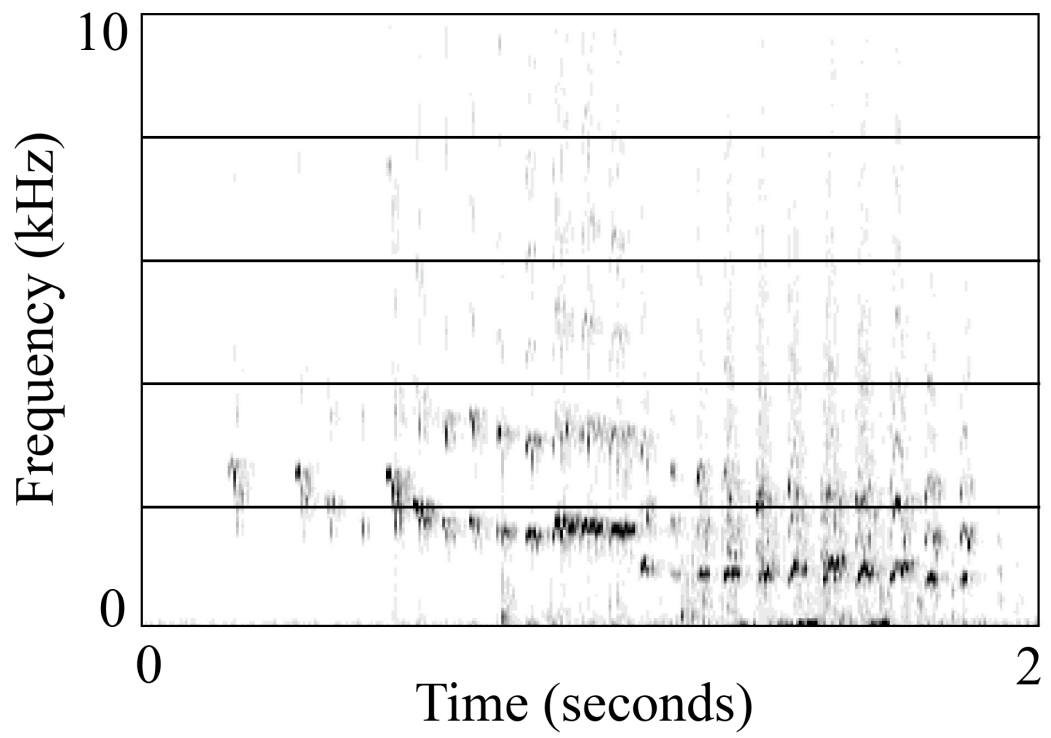


Fig. 7. Spectrogram of a tamarin alarm call.