Investigating the human-specificity of synchronization to music

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ABSTRACT

One universal of human music perception is the tendency to move in synchrony with a periodic beat (e.g., in dance). This response is not commonly observed in nonhuman animals, raising the possibility that this behavior relies on brain circuits shaped by natural selection for music. Consequently, if a nonhuman animal can acquire this ability, this would inform debates over the evolutionary status of music. Specifically, such evidence would suggest that this ability did not originate as an evolutionary adaptation for music. We present data from an experimental study of synchronization to music in a Sulphur-crested cockatoo (*Cacatua galerita eleanora*), "Snowball", who spontaneously dances in response to certain music (see YouTube: "dancing cockatoo"). Snowball's preferred song was presented at different tempi (original, +/- 2.5%, 5%, 10%, 15%, and 20%), and his rhythmic movements while dancing were quantified from video. The results reveal occasional bouts of synchronization at a subset of these tempi on ~20% of the trials. This demonstrates that a nonhuman animal can synchronize to a musical beat, though with limited reliability and tempo flexibility. These findings are consistent with the "vocal learning and rhythmic synchronization" hypothesis, which suggests that vocal learning provides the auditory-motor foundation for synchronization to a musical beat.

I. INTRODUCTION

Beat perception is a fundamental aspect of music cognition, and frequently elicits synchronized rhythmic movement in the form of tapping, swaying, head bobbing, or dancing. Moving rhythmically to a musical beat is observed in every human culture, making it one of the few true universals of human music (Nettl, 2000). A striking fact about this response to music is that it is not commonly observed in other animals. Furthermore, musical beat perception and synchronization (henceforth, BPS) does not appear to be a byproduct of other cognitive abilities such as language (Patel, 2006). There is currently keen interest in the human-specificity of BPS and whether it could represent a cognitive adaptation for music making (e.g., Merker, 2000; Patel & Iversen, 2006; Patel, 2008; Cross & Woodruff, in press; Fitch, in press). One way to test this idea is to determine if nonhuman animals are capable of BPS. Since nonhuman animals do not naturally make music (McDermott & Hauser, 2005), a demonstration of BPS in other species would indicate that this ability did not originate via natural selection for music.

A. Synchronized animal displays differ from BPS

Synchronized acoustic or visual displays are well known from the animal kingdom. For example, certain crickets, frogs, and fireflies are known to produce periodic signals in synchrony with neighboring conspecifics (Buck, 1988; Gerhardt & Huber, 2002, Ch. 8; Greenfield, 2005). Yet such displays differ from BPS in important ways. Notably, humans can synchronize to complex rhythmic stimuli (not just simple pulse trains), can sync across a wide range of tempi, and show cross-modal synchronization, with an auditory stimulus driving the motor system in periodic behavior that is not (necessarily) aimed at sound production. Synchronous animal displays do not show these features.

B. What kinds of brains are capable of BPS?

Because BPS involves tight integration between the auditory and motor systems, Patel (2006) proposed that only certain types of brains are capable of BPS. These are brains that are capable of complex vocal learning. Vocal learning requires a tight auditory-motor interface because it involves learning to produce complex acoustic signals based on auditory input during learning and auditory feedback during sound production (see Patel 2006 for further neurobiological details). This "vocal learning and rhythmic synchronization hypothesis" predicts that species without complex vocal learning (such as our primate cousins) are incapable of BPS, but that species with vocal learning (such as songbirds, parrots, dolphins, etc.) might be capable of BPS.

C. Apparent BPS in a nonhuman animal

In 2007 a video of a cockatoo dancing to music appeared on the internet (see YouTube: "dancing cockatoo"). The bird (named Snowball, Figure 1) appeared to be well synchronized to the musical beat, and quickly became an internet sensation (with over 3 million views to date). However, it was not clear if Snowball was receiving timing cues from humans (who might be dancing off-camera), or whether he could adjust his dancing to match different musical tempi (a key feature of BPS). To address these issues, we have conducted an experimental study of Snowball's dancing by adjusting the tempo of his preferred song and videotaping his dancing while ensuring that humans in the room were not dancing along with the music.

Figure 1. Snowball, a dancing sulphur-crested cockatoo

II. METHODS

A. Participant

Snowball is a male 12-year old medium sulphur-crested cockatoo (*Cacatua galerita eleanora*) [family Cacatuidae]. This species is native to Australia/New Guinea and is a member of the order Psittaciformes (parrots), a group of birds known for their vocal learning skills (Emery & Clayton, 2005). Snowball was relinquished to Birdlovers Only Rescue Service Inc. bird shelter in Schererville, Indiana, in August of 2007. His previous owner dropped him off with a CD and indicated that Snowball liked to dance to one of the songs. This was quickly confirmed, and two of the authors (IS and CS) have since repeatedly observed him dancing to this song as well as other songs.

Snowball is housed in a bird room with other medium and large parrots. A small T.V. and a multi-disc CD player are provided for entertainment in addition to numerous toys and parrot towers. Snowball's diet consists of Zupreem Fruit Blend pellets, Harrison's High Potency Pellets, Higgins Safflower Gold for large hookbills, Lafebers Nutriberries, pistachios, pine nuts, walnuts, and cashews.

B. Stimuli

A 1 minute 18 second excerpt of Snowball's preferred song ("Everybody", by the Backstreet Boys, a rock song in duple meter [4/4 time]) was manipulated using Audacity public domain software to create versions at 11 different tempi without shifting the pitch of the song: original, +/- 2.5%, 5%, 10%, 15%, and 20%. These were checked by ear to ensure that they were free of acoustic artefacts. The original tempo was 108.7 beats per minute.

C. Procedure and equipment

In study 1, three video sessions were conducted between January and early April 2008. For each session, Snowball was placed on the back of an armchair in the office of Birdlovers Only Rescue Service Inc. (one of his preferred dancing spots). A variety of tempi were presented in each session, typically by starting with the original tempo and then moving between manipulated tempi in a step-like fashion, from slow to fast. Short pauses were given between trials. On each trial Snowball was given verbal encouragement to dance, but humans did not dance with him, nor did he dance for a food reward. Sessions lasted about 1/2 hour and took place between 1 and 5 pm.

Study 2 consisted of two additional sessions late April and early May of 2008, using methods similar to study 1. The purpose of this study was to check if any synchronization found in study 1 could be due to Snowball imitating subtle rhythmic cues from humans. While no humans danced in study 1, one of the authors (CS) noted that IS had bobbed her head to the beat of the music in study 1. Hence in study 2 all rhythmic movements by humans in the room (such as head bobbing) were suppressed. Study 2 focused largely on the faster tempi, as it had been observed in study 1 that Snowball did not dance as readily to the slower tempi.

In both studies music was presented via Altec Lansing Series 5100 speakers connected to a personal computer. Videos were taken with a Panasonic Mini DV camera mounted on a tripod, approximately 6 feet from Snowball. After each session, the video was transferred to a personal computer and then burned to disc as a .wmv files for analysis.

D. Data analysis

Videos were segmented into individual trials ranging from 0:47 to 1:38 in length. Each segment was deinterlaced to obtain 60 frame-per-second time resolution (deinterlacing was not possible for video 2, which thus had 30fps resolution). Snowball's rhythmic movements were coded with the sound turned off and with the coder unaware of which condition the trial represented. Although several different classes of rhythmic movements were observed, including head bobbing, foot lifting, and side-to-side head movements, vertical head position was found to be the most reliable rhythmic gesture. (Notably, this same measure was recently chosen in human studies of rhythmic movement to music, Eerola, Luck, & Toiviainen, 2006.) To study the timing of head bobs, each frame number was noted in which Snowball's head reached a locally minimal position in the vertical plane.

Audio tracks were extracted for each trial and beat times were found using a beat tracking algorithm (Ellis, 2007). The performance of the algorithm was evaluated by author JI (an experienced drummer) by listening to synthesized click tracks. Rare periods when the beat track was judged inaccurate were excluded from analysis (this only affected ~10s at the end of one trial).

Beat times were quantized to the nearest video frame for evaluation of movement synchrony (hence the temporal resolution of the beat tracker was 1/60s [1/30s in video 2]). Each head bob was assigned phase relative to the closest auditory beat. For example, a head bob coinciding with an auditory beat was assigned a phase of 0, a bob 25% of the beat period ahead of a beat was assigned a phase of -90 degrees, and a bob 25% of the beat period after the beat was assigned a phase of 90 degrees. Each bob thus defined a phase vector, i.e., a vector on the unit circle with a particular angle. Since Snowball did not dance continuously throughout each trial, the percent of each trial's duration which was occupied by rhythmic movements was also quantified, as a measure of how much Snowball danced.

To assess Snowball's synchronization to the beat, the phase vectors in each trial were analyzed in two ways. First a global measure of synchrony was obtained by finding the length and angle of the mean phase vector. The Rayleigh test (Fisher, 1983:69) was applied to these vectors to determine whether statistically significant synchrony existed within the trial (p<.05). Throughout this paper we use a version of the Rayleigh test that is sensitive both to the consistency of the phase angle from beat to beat, and the distance of the mean phase angle from 0 (perfect synchrony). Hence our statistical test of synchrony is concerned with both the period and the phase of rhythmic movements with respect to the musical beat.

Observation of entire runs suggested that there were periods of synchrony ("synchronized bouts") interspersed with periods where Snowball was dancing but was not synchronized to the music. To identify the location and extent synchronized bouts, a windowed analysis was used in each trial. Eight gestures at a time were used to compute a mean phase vector, whose length and angle were recorded. Windows were overlapped by half, yielding approximately 25 windows per trial. The Rayleigh test

was applied to the mean vector in each window. Regions with at least 2 successive windows showing significant entrainment (p<0.05) were identified as synchronized bouts. These bouts were used to compute Snowball's strength of entrainment via the length and angle of the mean phase vector during the bouts.

III. RESULTS

A. Study 1

Table 1 shows the tempi of trials that produced usable data in study 1. A few tempi/trials in each given video session did not produce usable data because Snowball did not dance or because of problems with the recording (these are not represented in the table). Note that in some cases, a session had more than 1 usable trial at a given tempo. Trials in which Snowball showed statistically significant entrainment based on the global measure of synchrony are shown in bold.

Table 1: Trials in study 1. Trials with overall significant entrainment are shown in bold. p-values in parentheses.

Video 1		Video 2		Video 3	
- 10 %		- 20 %,		- 20 %,	
- 5 %		- 20 %		- 15 %	
- 2.5 %	(<.03)	- 15 %		- 10 %	
- 2.5 %	(<.01)	- 10 %		- 5 %	
100 %		**-5 %**	(<.001)	100 %	
5 %	(<.001)	**-2.5 %**	(<.001)	5 %	
10 %	(<.001)	100 %		10 %	
15 %		**100 %**	(<.001)	15 %	
20 %	(<.001)	2.5 %		20 %	
		5 %			
		10 %			
		15 %			
		20 %			

Snowball showed significant overall entrainment on 8/31 trials. Closer inspection of these trials, however, revealed that in two of these trials (video 2 , -5% and 100%) synchronization bouts had frequent pauses between successive rhythmic gestures, so that synchronization was not sustained. Hence 6/31 trials (about 20%) contained sustained periods of synchronization.

Further analysis focused on these 6 trials, quantifying aspects of Snowball's rhythmic movements. Relevant data are presented in Table 2. As is evident in the table, Snowball danced during most of each trial, producing over 100 rhythmic head bobs each time. The percent of these gestures that were part of synchronized bouts ranged from 14% to 50% on any given trial, and the longest synchronized bout in each trial ranged from 16 to 32 beats. During such bouts, Snowball's dance tempo is close to the musical tempo, and he shows strong entrainment to the beat (long phase vector length) and a phase angle which is typically slightly ahead of the beat, indicating that he was anticipating the beat rather than reacting to it. Notably, the p-values for the Rayleigh test during synchronization bouts show extremely high degrees of significance (e.g., $p = 10^{-5}$).

Table 2. Data from study 1

	-2.5 %	-2.5 %	-2.5 %	5 %	10 %	20 %
% of trial spent dancing	97	94	69	87	85	95
# gestures coded	139	118	100	104	109	120
% of gestures in sync bouts	17	14	20	40	33	50
Length of longest sync bout (in beats)	24	16	20	28	24	32
Music BPM	106	106	106	114	120	130
Snowball BPM in sync bouts (mean, sd)	106 (6)	110 (4)	110 (8)	115 (14)	122 (12)	129 (17)
Phase vector length in sync bouts (max = 1)	.96	.85	.82	.89	.88	.82
Phase vector angle (degrees)	-51	-22	-37	-7	-17	4
Rayleigh p-value exponent 10^x	-7	-3	-5	-13	-10	-15

B. Study 2

In study 2 all human movement to the beat of the music (e.g. head bobbing) was suppressed, to eliminate imitation as the source of Snowball's rhythmic movements. Only ~50% of the trials presented in study 2 have been analyzed thus far. Analyzed trials are listed in Table 3, which follows the conventions of Table 1.

Table 3: Analyzed trials from study 2. Trials with overall significant entrainment in bold. p-values in parentheses.

Video 4		Video 5	
- 2.5 %		**- 2.5 %**	(.001)
10 %		2.5 %	
15 %		10 %	
15 %	(<.02)	**15 %**	(.03)
		20 %	(<.03)

Snowball showed significant entrainment on 4/9 analyzed trials in study 2. Closer inspection of these trials, however, revealed that in one of the trials (video 5, 20%) synchronization bouts had frequent pauses between successive rhythmic gestures, so that synchronization was not sustained. Hence 3/9 trials (about 33%) contained sustained periods of synchronization. Further analysis focused on these trials. Relevant data are presented in Table 4, which follows the conventions of Table 2.

In contrast to study 1, Snowball danced less during each trial in study 2 and produced fewer rhythmic gestures overall. However, within each trial the percent of gestures that were part of synchronized bouts was comparable to study 1, as were the lengths of the longest synchronized bouts. Once again, during synchronized bouts Snowball's dance tempo was close to the musical tempo. Entrainment to the beat (phase vector length) was a bit weaker than in study 1, though still statistically highly significant. The phase angle was closer to 0 than in study 1.

Table 4. Data from study 2

	-2.5 %	15 %	15 %
% of trial spent dancing	76	64	54
# gestures coded	101	89	78
% of gestures in sync bouts	36	31	51
Length of longest sync bout (in beats)	24	20	16
Music BPM	106	125	125
Snowball BPM in sync bouts (mean, sd)	105 (6)	126 (12)	122 (9)
Phase vector length in sync bouts (max = 1)	.87	.84	.67
Phase vector angle (degrees)	2	-8	5
Rayleigh p-value exponent 10^x	-7	-7	-6

C. Tempo sensitivity of Snowball's dancing

Figure 2 shows musical tempo vs. Snowball's tempo in beats per minute (BPM) during synchronized bouts in the 9 trials examined across the two studies. (Two of the data points for -2.5% trials lie directly atop each other, hence only 8 points are visible in the graph.) The regression line relating these two variables is also shown, and is highly significant (p<.0001). Illustrative video clips are available to view at http://www.nsi.edu/users/patel/publications.html.
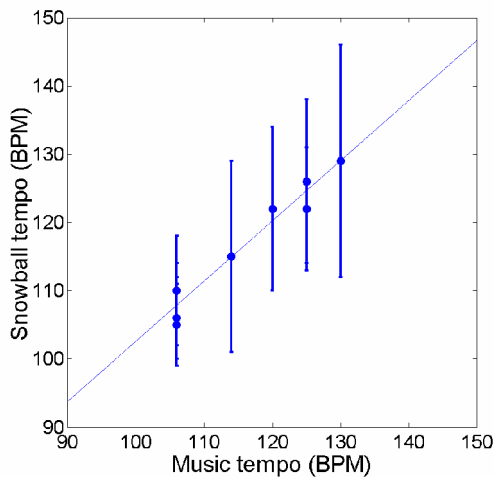
Figure 2. Music tempo vs. Snowball's tempo (in beats per minute, BPM) for synchronized bouts across a range of musical tempi. Data from 9 trials are represented in the graph. Error bars show standard deviations. The best fitting regression line is shown: Snowball BPM = 0.88*Music BPM + 14.4, r^2 = .95 (p<.0001). The original tempo of the song was 108.7 BPM.

IV. DISCUSSION

A. Cognitive significance

This study shows that beat perception and synchronization (BPS) is not a uniquely human phenomenon. A sulphur-crested cockatoo shows spontaneous BPS to human music, and also shows spontaneous adjustment of movement tempo to match tempo manipulations of music. These findings suggest that BPS did not originate as a brain specialization for music, but is instead a latent ability in certain types of brains. The current findings are consistent with the idea that brains capable of BPS are those that have been shaped by natural selection for vocal learning, which creates a tight auditory-motor interface in the nervous system (Patel, 2006; 2008).

It is noteworthy that Snowball mostly synchronized with versions of the song at its original or faster tempi (though he was capable of synchronization at one tempo slightly slower than the original), suggesting a limited range of entrainment. Furthermore, even during trials where sustained synchronization was evident, Snowball synchronized for a minority of the time that he was dancing. The above facts suggest that Snowball may have his own preferred tempo for rhythmic movement, which he can adjust slightly. This would allow him to entrain to the music with a limited degree of flexibility. Preferred tempi for rhythmic movements are well known from human studies, with faster movements typically being observed in younger children (McAuley et al., 2006).

At present it is unclear why Snowball does not synchronize at slower tempi or for longer time periods at the original or faster tempi, given his ability for sustained synchronization to a musical beat. Whether the key factors are attention and motivation, or are motor limits on synchronization ability, require further research.

B. How did it emerge?

Snowball's previous owner (PO) acquired him at a bird show when Snowball was 6, and the details of the bird's life and experience with music prior to this are not known. The PO mentioned that soon after he acquired Snowball, he noticed Snowball bobbing his head to the music of the Backstreet Boys (the PO felt that this was not done in imitation of human movement). Subsequently, the PO and his children began to encourage Snowball's dancing, partly by making rhythmic arm gestures to the beat of the music. Soon thereafter Snowball quickly developed his own rhythmic foot-lifting behavior, perhaps in imitation of the human arm gestures. Since that time, Snowball has danced to "Everybody" and to other rock songs with a steady beat.

C. Could it have happened by chance?

Since Snowball shows sustained synchronization to the beat for the minority of time on any given trial (and on a minority of trials), an important question about these findings is whether they could have happened by chance. It is quite clear that Snowball moves rhythmically in response to music with a beat. Could it be, however, that he has a preferred tempo which is only weakly perturbed by the musical tempo, and that due to natural variability in his dance tempo within a trial, our analyses are picking out times that (by chance) his own movements happen to have a consistent temporal relationship with beat? We are currently investigating this issue, and developing methods to estimate the likelihood that our findings could have arisen by chance. [Note added in proof: the statistical issues

raised in this section have been addressed using Monte Carlo methods, and it appears unlikely that our results could have arisen by chance (p< .03). See Patel, Iversen, Bregman, Schulz, and Schulz, 2008.]

D. Issues for future research

These findings raise a wide range of questions, a few of which are mentioned here. First, what range of music (in terms styles and tempi) can Snowball synchronize to, without human rhythmic movement cues to guide him? Second, do his different movement modes (e.g., head-bobbing, foot-lifting, side-to-side head movements) mark out different levels of the metrical hierarchy? Third, what is the relationship of his dance movements to the natural display movements of cockatoos? (That is, is he simply adapting existing movements, or inventing new ones?). Fourth, what influence do social cues have on his synchronization abilities? Informal evidence suggests that his synchronization improves when dancing with a human vs. when dancing alone. It will be interesting to determine whether the range of tempi to which Snowball can synchronize is expanded when dancing with a partner.

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