Proceedings of the 10th International Conference on Music Perception and Cognition (ICMPC 10). Sapporo, Japan.
Ken'ichi Miyazaki, Yuzuru Hiraga, Mayumi Adachi, Yoshitaka Nakajima, and Minoru Tsuzaki (Editors)

The Beat Alignment Test (BAT): Surveying beat processing abilities in the general population

John R. Iversen[1] and Aniruddh D. Patel[2]

The Neurosciences Institute, San Diego, CA, USA

[1]iversen@nsi.edu, [2]apatel@nsi.edu

ABSTRACT

The ability to perceive a musical beat (and move in synchrony with it) seems widespread, but we currently lack normative data on the distribution of this ability in musically untrained individuals. To aid in the survey of beat processing abilities in the general population, as well as to attempt to identify and differentiate impairments in beat processing, we have developed a psychophysical test called the Beat Alignment Test (BAT). The BAT is intended to complement existing tests of rhythm processing by directly examining beat perception in isolation from beat synchronization. The goals of the BAT are 1) to study the distribution of beat-based processing abilities in the normal population and 2) to provide a way to search for "rhythm deaf" individuals, who have trouble with beat processing in music though they are not tone deaf. The BAT is easily implemented and it is our hope that it is widely adopted. Data from a pilot study of 30 individuals is presented.

I. INTRODUCTION

We present an easily used test of musical beat perception and synchronization, aimed at quantifying the normal range of beat-based processing abilities in the general population. While the ability to perceive a musical beat (and move in synchrony with it) seems widespread, we currently lack large-sample normative data on the distribution of this ability in musically untrained individuals.

The Beat Alignment Test (BAT) is distinguished by its focus on synchronization with musical passages of a variety of genres. It is designed to be naturalistic and simple, yet comprehensive. It includes several subtests: spontaneous tapping, synchronization to a metronome, synchronization to musical passages, and a perceptual test of beat perception in musical passages. The tests are described fully in Section II.

One goal of the BAT is to provide a means to identify and classify patterns of deficits in beat-based processing, as a way to test hypothetical beat-processing mechanisms. As synchronization with a beat involves both the perception of a beat as well as the motor expression of this internally perceived beat, a question of interest is how tightly coupled are beat perception and production? Can normal beat perception exist in the face of poor motor synchronization, or does poor synchronization imply poor beat perception? The BAT was designed to allow the possibility of dissociation between perceptual and motor processes by testing beat perception without requiring the listener to express the beat through movement. Evidence for a similar kind of dissociation between deficits in pitch perception and production has recently been found (Dalla Bella, et al., 2007; Loui, et al., 2008).

Another goal of developing the BAT is to have a way to search for purely "rhythm deaf" individuals, who have trouble perceiving a beat in music though they are not tone deaf. Do such people exist? Using the BAT in conjunction with tests of tone deafness (e.g., the Montreal Battery for the Evaluation of Amusia; MBEA) provides one way to address this issue. While amusics are often impaired rhythmically (Dalla Bella and Peretz, 2003), it has been suggested that this deficit is a consequence of pitch impairments (Foxton, et al. 2006). Recently, research using the MBEA in conjunction with the BAT test and another novel test of rhythm perception has found evidence for rhythm impairments independent of pitch impairments (Thompson, et al. 2008). A central question is whether listeners' abilities vary along a continuum, or if distinct types of deficits exist.

The BAT falls within a tradition of measuring motor synchronization to auditory stimuli (Repp, 2005). Relatively few such studies have examined synchronization to musical passages (Drake et al., 2000) and those that have examined synchronization often used only musically trained participants (e.g. Synder & Krumhansl, 2001).

The primary innovation of the BAT lies in a purely perceptual test of beat perception (i.e., one which does not require overt synchronization). Existing perceptual tests of musical rhythm perception do not address beat perception directly, and typically proceed by asking listeners to discriminate between two successively presented rhythms (e.g., Seashore, 1960). The BAT attempts to assess beat perception by testing if listeners can detect whether a click track presented simultaneously along with musical excerpts is on or off the beat of the musical excerpt.

II. METHODS

The BAT consists of three sections. The first assesses basic synchronization abilities in a traditional manner, measuring spontaneous tapping as well as synchronization with a simple metronome. The second assesses synchronization with a musical beat. The third section tests perception of a beat.

A. Test Design

1) Part 1: Synchronization with a metronome

First, baseline data on synchronization ability are collected. This includes two 30-second samples of even tapping at a preferred tempo, and synchronization with a simple metronome at multiple tempi (400, 550 and 700ms IOI, 30 second duration.)

2) Part 2: Synchronization with the beat of music

The second part of the BAT tests the ability to tap with the beat of music. Twelve instrumental musical excerpts from a range of genres are used (II. B and Table 1). Participants listen to each excerpt two times (in a row) and are instructed to tap to the perceived beat. Tap times are collected and the accuracy and variability of synchronization are measured. As

participants may choose different tactus levels with which to synchronize, tapping performance is compared not to some absolute excerpt tempo, but to the excerpt tactus level closest to the tapping tempo (referred to as tactus inter-onset interval; Tactus IOI). The order of the stimuli is randomized for each participant. After the second presentation of a given excerpt, the participant is asked to rate the familiarity of the excerpt, where 1 = never heard it, 2 = somewhat familiar, 3 = very familiar.

3) Part 3: Perceptual judgment of the beat

The third part of the BAT assesses beat perception separately from overt synchronization. Participants listen to each excerpt without tapping and try to decide if an evenly-timed train of beeps superimposed on the music sounds "on the beat" or not. Each excerpt occurs in three versions: one with beeps on the beat, and two with beeps off the beat. For each excerpt, one of the off-beat versions has beeps that are either too fast or too slow in tempo ("tempo error" condition), and the other off-beat version has beeps that are out of phase with the actual beat (either early or late; "phase error" condition). Across the 24 trials with off-beat beeps, there are 6 trials each of: beeps too fast, beeps too slow, beeps early, and beeps late. The order of the stimuli is randomized for each participant.

While listening to an excerpt, participants indicate (by a button press) as soon as they have made their judgment, to quantify the time taken to make the judgment. After the excerpt has finished, percipients are asked what their judgment was: (are the beats on or off the beat? answering Y or N). Listeners are also asked to rate the confidence of their judgment, where 1 = guessing, 2 = somewhat sure, 3 = completely certain. Before starting this part of the experiment, participants were familiarized with the sound of the beeps by hearing them alone. Note also that participants are instructed not to move in any way to keep the beat. (Anecdotally, many participants reported that it was difficult not being allowed to move rhythmically during the perception test.)

Finally, participants fill out a questionnaire to describe their level of musical and physical performance as well as their listening expertise.

B. Stimuli

Musical excerpts were taken from several genres (Table 1). Average musical excerpt duration is 15.9 s, SD = 3.1 s. Stimuli are 44.1 KHz (CD, mono). The amplitude of each musical excerpt ramps up and down at its beginning and end (over 500 ms).

In the third part of the test, beeps (1 KHz pure tones, 100 ms duration) are superimposed on the excerpts, starting after 5 seconds of music have elapsed, and continuing until ~1 second before the music ends. The timing of the beeps for the 'on-the-beat' condition was based on taps made by one author (JI, an amateur drummer), averaged across 6 trials per excerpt. The mean ITI for each excerpt was calculated, and an isochronous pulse train was generated, aligned with the average time of the first tap more than 5 seconds from the start of the excerpt.

Tempo-error stimuli were created in the same way, but using an ITI either 10% shorter or longer than the on-the-beat version. Phase-error stimuli used the on-the-beat ITI, but beeps were advanced/delayed by 25% of the ITI.

Table 1. Musical excerpts used in the BAT.

Style	Piece	Artist
Rock	Hard to handle	Black Crowes
Rock	One way or another	Blondie
Rock	Hurts so good	J. Mellencamp
Rock	Panama	Van Halen
Jazz	1 o'clock jump	Benny Goodman
Jazz	Stompin' at the savoy	Benny Goodman
Jazz	Tuxedo junction	Glenn Miller
Jazz	King Porter stomp	Glenn Miller
Pop Orchestral	NY, NY	Boston Pops
Pop Orchestral	A chorus line	Boston Pops
Pop Orchestral	Superman	Boston Pops
Pop Orchestral	Richard Rogers Waltzes	Boston Pops

III. RESULTS

A small pilot study of 30 individuals shows that the BAT test is easily understood by people with little or no musical background. Participants were adults drawn from the local community who had a range of music experience from professional to self-declared amusic. In this section we present results for music synchronisation, for the beat perception test, and then examine the correlation between performance on the two types of task. These results are not meant to be comprehensive, and are intended to illustrate the types of analysis that may illuminate rhythm deficits once a much larger sample has been collected.

The test was implemented using Presentation (Neurobehavioral Systems, Inc.) for stimulus delivery and response collection. Synchronization was collected using a MIDI drum pad (Roland SPD-6) on which participants tapped using their dominant hand.

A. Synchronization

Participants tapped along with 12 musical excerpts, each presented twice. Participants were generally successful at finding some kind of beat in most of the excerpts; the worst case was one listener who failed to find any beat in two of the classical excerpts.

Two simple analyses are presented: 1) the ability to match tapping rate to the tempo of the musical excerpt, and 2) the variability of tapping. Figure 1 shows the mean inter-tap interval (ITI) compared with excerpt tempo (inter-onset interval of the tactus level closest to the tapping tempo; "Tactus IOI") for two participants. Each point represents performance for one trial of an excerpt. The participant shown in solid symbols showed nearly perfect matching of tapping tempo to the music tempo (correlation coefficient = 0.99; $p<0.0001$). The participant with the worst tempo performance is shown in open symbols (correlation coefficient = 0.66). Though the dispersion is greater, tempo sensitivity is clearly evident ($p<0.002$). (Note also that the second participant generally chose to synchronize with a slower tactus level. Tactus level is not analysed further here but is another dimension of interest.)

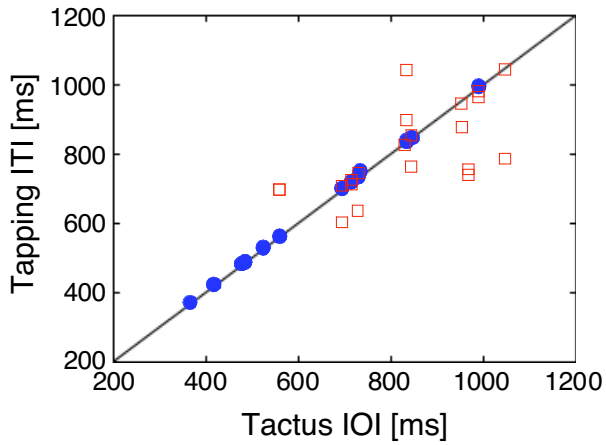

Figure 1. Examples of synchronization accuracy for two participants. Inter-tap interval (ITI) is plotted versus the tactus inter-onset interval (IOI) of the musical excerpt for all excerpts. Shown are a participant with nearly ideal tempo accuracy (filled circles) and the participant with the worst tempo accuracy (open squares).

Figure 2 shows synchronization ITI for all excerpts and all 30 participants. The overall correlation coefficient is 0.98 ($p<0.0001$).

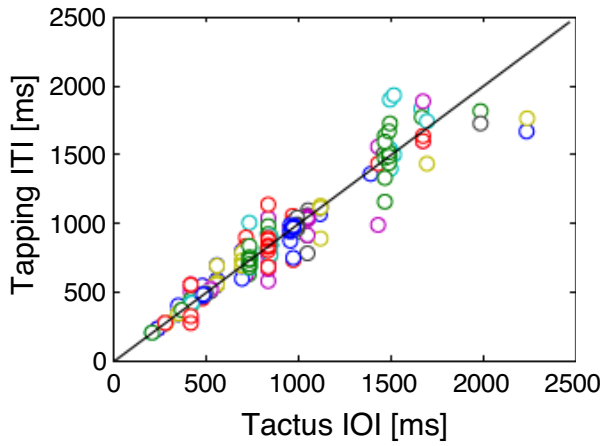

Figure 2. Synchronization performance across all participants and excerpts. Tapping ITI is plotted versus the tactus IOI of the musical excerpts, as in Figure 1.

B. Beat Perception

In the test of beat perception, participants judged whether a click track superimposed on the musical excerpts was on the beat or not. The superimposed click track could be either truly on the beat ("On beat") or be off the beat with the wrong tempo ("Tempo error") or wrong phase ("Phase error"). Figure 3 shows overall population performance for the three conditions (performance for each participant was averaged across all 12 excerpts). All participants correctly identified the on-beat click tracks the majority of the time (mean percent correct = 90%). Performance on tempo and phase error conditions were both significantly worse than the on beat condition, indicating participants were more likely to incorrectly judge an off-beat click track as being on the beat than they were to judge on-beat clicks to be off the beat.

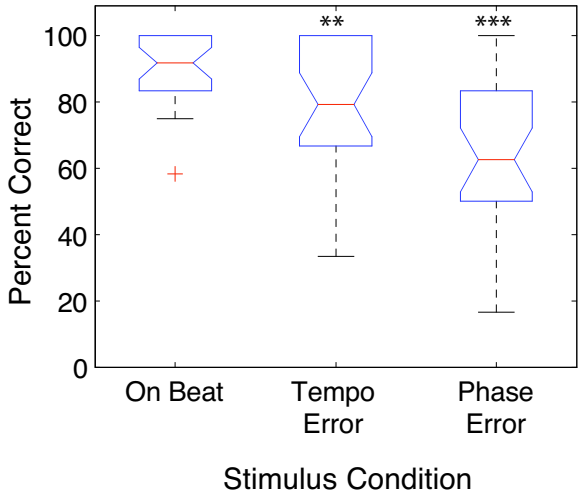

Figure 3. Beat perception performance across all 30 participants for three beat alignment conditions: on beat, tempo error, and phase error.

C. Comparison of musical beat synchronization and perception

One rationale for the BAT was to compare performance in beat perception and beat synchronization tasks, to determine if there were dissociations between these two behaviours. Figure 4 shows a global measure of synchronization performance, the correlation of tapping tempo with music tempo for each participant, versus the participant's overall performance on the beat perception task. Notably, the majority of participants tracked tempo very faithfully (28 of 30 had correlation coefficient > 0.9). Behavioural scores are distributed nearly uniformly from chance to perfect, indicating that the test was challenging. One outlier suggests a dissociation between motor synchronization (relative poor tempo tracking) and perception (average performance). (The outlier is the participant shown in Figure 1.) Overall there is a weak correlation of the two (correlation coefficient = 0.38; $p<0.03$; the correlation is stronger if the outlier is removed: 0.56; $p<0.001$).

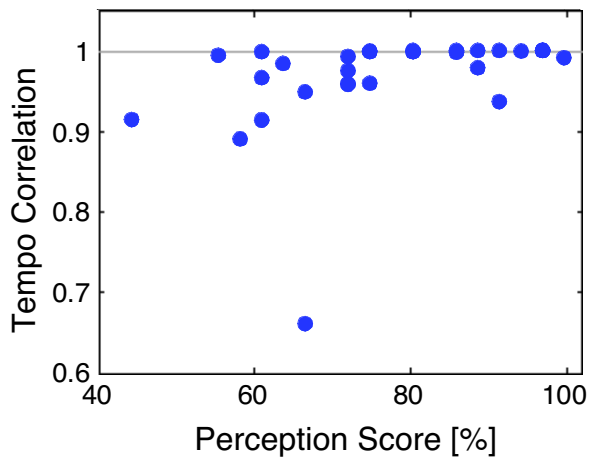

Figure 4. Correlation of tapping tempo and musical excerpt tempo vs. score on the perceptual task.

A second type of behavioural measure examines the variability of synchronization from beat to beat (as opposed to the more global measure of tempo accuracy). While there are many possible measures of this, as a start, the mean coefficient of variation of the inter-tap intervals (ITI CV) was computed for each participant (averaging across all excerpts for a given participant). ITI CV varied over a wide range from 3% to 12%, with a mean of 6% (sd 2.2%) across participants. Figure 5 compares tapping variability (ITI CV) with beat perception performance. The two are highly correlated (correlation coefficient = -0.61; $p<0.001$), indicating that poor beat perception covaries with tapping variability.

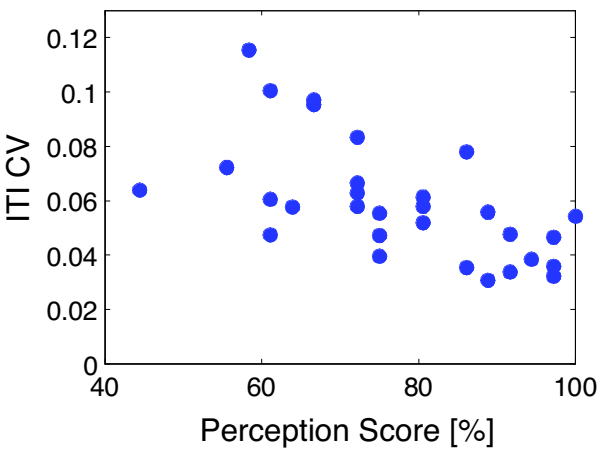

Figure 5. Mean tapping variability (Coefficient of variation of ITI) vs. score on perceptual task for each participant.

IV. CONCLUSION

We have described the BAT, a test battery deigned to assess musical beat-processing abilities in the general population. The test assesses both the ability to synchronize with a beat in music, as well as the ability to perceive a beat independently of synchronization.

Results from a small pilot sample are presented. The test was judged successful because it was easily understood by all participants, independent of musical experience. In addition, both behavioral and perceptual measures showed a wide distribution of performance, indicating that the test was neither too easy nor too difficult.

Listeners demonstrated a wide range of abilities in synchronization and in judgments of beat alignment. In this small sample, synchronization accuracy and accuracy of perceptual judgments were largely correlated, though this link remains to be explored more fully. A larger sample will be required in order to accurately describe the population distribution and to isolate interesting outliers.

Materials to implement the BAT test are freely available at http://www.nsi.edu/users/iversen/bat/BAT_TEST.zip and we welcome suggestions for improvement.

ACKNOWLEDGMENT

We thank Heidi Moomaw for her help in selecting the musical excerpts for the BAT. This work was supported by Neurosciences Research Foundation as part of its program on music and the brain at The Neurosciences Institute, where JRI is the Karp Foundation Fellow and ADP is the Esther J. Burnham Fellow.

REFERENCES

Dalla Bella, S., Giguère, J. F., and Peretz, I. (2007) Singing proficiency in the general population. *J Acoust Soc Am, 121*, 1182-9.

Dalla Bella, S. and Peretz, I. (2003). Congenital amusia interferes with the ability to synchronize with music. *Ann N Y Acad Sci 999*, 166-9.

Drake, C., Jones, M. R., and Baruch, C. (2000). The development of rhythmic attending in auditory sequences: attunement, referent period, focal attending. *Cognition 77*, 251-88.

Foxton, J. M., Nandy, R. K., and Griffiths, T. D. (2006). Rhythm deficits in 'tone deafness'. *Brain and Cognition 62,* 24-9.

Loui, P., Guenther, F. H., Mathys, C., and Schlaug, G. (2008). Action–perception mismatch in tone-deafness. *Current Biology* 18, R331-2.

Peretz I., Champod, A. S., and Hyde, C. (2003). Varieties of musical disorders. The Montreal Battery of Evaluation of Amusia. *Ann N Y Acad Sci 999*, 58-75.

Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin & Review 12*, 969-992.

Seashore, C. B., Lewis C., and Saetveit, J. G. (1960). *Seashore measure of musical talent*. New York, NY: Psychological Corporation.

Snyder, J. and Krumhansl, C. L. (2001). Tapping to ragtime: cues to pulse finding, *Music Perception 18*, 455 – 489.

Thompson, W. F., Sigmundsdottir, L., Iversen, J. R., and Patel, A. D. (2008). Selective rhythmic impairments in music. *10th International Conference of Music Perception and Cognition*, Sapporo, Japan.