1-1-2022

Melody, not Beat Perception, Predicts Rhythmic Error Detection

Laura A. Stambaugh

Bryan E. Nichols

Citation
Nichols, B. E. & Stambaugh, L. A. (2022). Melody, not beat perception, predicts rhythmic error detection. Journal of Research in Music Education, 70(2), 190-205. https://doi.org/10.1177/00224294211032160

Original Research Article

National Association *for* Music Education

Melody, not Beat Perception, Predicts Rhythmic Error Detection

Journal of Research in Music Education
2022, Vol. 70(2) 190–205

DOI: 10.1177/00224294211032160
jrme.sagepub.com
SAGE

Bryan E. Nichols[1] **and Laura A. Stambaugh**[2]

Abstract

The purpose of this study was to examine the relationships among beat perception, error detection, and musical experience. We presented monophonic rhythms using a piano timbre along with two measures of beat perception (Harvard Beat Finding and Interval Test [BFIT] and Goldsmiths Beat Alignment Test) and a measure of melodic error detection. College musicians' (N = 43) ability to detect rhythm errors was not significantly correlated to their ability to perceive beat alignment (Goldsmiths test) or tempo change (BFIT). Age was related to performance on only one of the measures, the BFIT test. A regression model yielded pitch error detection as the only significant predictor of rhythmic error detection. We suggest that college musicians already possess a requisite ability for beat processing that allows them to perform error detection. The lack of relationship between beat perception and rhythmic error detection is explained by this requisite ability in the population, and we promote future research for pitch and rhythm processing as it relates to rhythm perception or performance.

Keywords

error detection, beat perception, timekeeping, pulse

Music education students are generally required to pass a sequence of music theory and/or aural skills courses. Two requisite skills developed in theory and/or aural skills courses are beat perception and rhythm perception. They serve as a foundation for more advanced skills needed by music teachers, such as error detection, which is used

[1]The Pennsylvania State University, University Park, PA, USA
[2]Georgia Southern University, Statesboro, GA, USA

Corresponding Author:
Bryan E. Nichols, The Pennsylvania State University, 105 Music Bldg 1, University Park, PA 16802, USA.
Email: bnichols@psu.edu

by music teachers every day. Musicians need to be able to extract a beat (beat perception) from what is heard, and here we examine this ability alongside ability in rhythmic error detection. Previous research suggests a relationship between melodic interval identification and melodic error detection (Stambaugh & Nichols, 2020). The purpose of this study was to extend that research by exploring whether a similar relationship existed between beat perception and rhythmic error detection ability.

Beat Perception

The terms *tactus*, *pulse*, and *beat* tend to be used interchangeably for identifying a temporal organization or periodicity in music (London, 2011). *Beat perception*, *beat extraction*, *beat induction*, and *timekeeping* refer to the process of listening to music and identifying the underlying beat or pulse. Recently, Kung (2017) applied a cultural lens, arguing that beat is derived from notational systems, whereas pulse is suitable for both notation-based and aural-based music systems. Because the context of the current study is error detection in Western-based music scores, we intentionally use the term *beat*. In addition, we focus on beat perception, not beat or rhythm production. Although the abilities to perceive beat and produce beat are often highly related, the two skills are not interchangeable (Fujii & Schlaug, 2013; London, 2011; Matthews et al., 2016). It is likely that the act of producing a steady beat, whether tapping, playing an instrument, or singing, engages motor aspects of the brain and provides feedback that is not available during purely perceptual tasks (Fujii & Schlaug, 2013).

Behavioral and neuroscientific research has been conducted to examine how the brain perceives beat and pulse. Much of this research, however, is centered on relationships between perceptual phenomena and the brain rather than how this information might apply within pedagogical contexts (e.g., Potter et al., 2009). Results of such research usually do not make their way into music education journals because it would be premature to use them to derive pedagogical implications. Instead, we give a very summative account of two theories of timing that are informed by basic research. One model is commonly referred to as an *interval* or *clock* model (e.g., Povel & Essens, 1985). During a given duration of interest, a continuous stream of internal pulses collects into an accumulator (McAuley, 2010). These collections are stored as references in long-term memory. When a new duration is encountered, it is compared to these references. The other prevalent model for timekeeping is *entrainment* (e.g., Jones, 1976; van Noorden & Moelants, 1999), closely related to dynamic attending theory (e.g., Henry & Herrmann, 2014). Music is an external force that provides a rhythm. Internally, neurons fire in waves or oscillations. Instead of comparing timing data to long-term memory references, we compare the music beats to the peaks of the neural oscillations. The music beats will either align or not align with the oscillation peaks.

Returning to musical contexts, the ability to extract a beat from music is not only dependent on subtle accents existing in a meter but also can be affected by volume, register, event density (number of aural events happening in a window of time), and cultural background of the listener (Bouwer et al., 2018; Drake et al., 1999; London, 2011; van Noorden & Moelants, 1999). Furthermore, the hierarchical structure of Western rhythms allows listeners to choose different levels of beat. Generally, composers and listeners will choose beats happening at the rate of 80 to 120 beats per minute (bpm; McAuley, 2010; Thompson & Schellenberg, 2002). Below 60 bpm, people may extract a beat that is actually a subdivision, and above 120 bpm, they may choose a macrobeat composed of multiple beats (e.g., choosing Beats 1 and 3 in a 4/4 pattern; Duke et al., 1991).

A next step in beat and rhythm research is to examine the relationships between complex musicianship skills and their relevant component skills. Recently, Farley (2014) investigated how the basic skill of beat keeping related to the more complex skill of rhythm sight-reading in university instrumentalists. She found significant moderate to strong correlations among three beat-keeping tests. Generally, participants either slowed down or sped up within a trial rather than having inconsistent beat durations. Beat-keeping ability was not significantly related to participants' ability to sight-read rhythmic exercises. The overall import of this work is that it tested the musical executive function of timekeeping in relation to the applied skill of rhythmic sight-reading. Our current study extends Farley's work by examining relationships between beat perception and rhythmic error detection.

Error Detection

Although sight-reading research can inform other, separate inquiries about rhythm perception and performance, it is important to describe error detection as distinct from sight-reading. Whereas sight-reading requires both the interpretation of visual information (reading) and translating the information to motor activity (performance), it may also include the processing of auditory information (listening) to evaluate one's performance (Clark & Williamon, 2011). Error detection does not require musical motor activity, leaving just the reading component and the listening component. Furthermore, error detection can occur without the reading component when the listener is already familiar with the stimuli, leaving just an auditory processing (listening) component. However, most reports of error detection ability come from designs where participants manage both tasks; in other words, what is known about error detection is what we know from studies where participants monitor notated music along with aural stimuli. Buonviri (2019) compared dictation, which requires music students to interpret an aural "target" and transfer it to notation, to error detection, which requires students to interpret an aural target and compare it to given notation, and also to sight-singing, which requires students to interpret an aural target and then realize it vocally. In a review of literature on musicianship preparation, Davis (2010) used the term *sight-hearing* for audiation or imagery in comparing what is heard to what is seen, and the term *error-correct* has been used to describe a musician's need to detect and correct errors (Nichols et al., 2018), or the identification of "melodic fragments" (Nichols & Springer, 2021), particularly among conductors (Wöllner & Halpern, 2016).

Researchers have investigated many factors affecting error detection ability. Error detection is shown to improve with age or experience, and the addition of parts increases the difficulty, as does the use of polyrhythmic texture (Byo, 1993, 1997). Additional listenings to stimuli increase the occurrence of false positives (Sheldon, 2004). Additionally, undergraduate majors were more accurate at identifying errors within their own performance domain (band vs. choral in Stambaugh, 2016). Tonal and atonal contexts significantly affect performance (Groulx, 2013), with further significant differences shown between diatonic and chromatic pitch conditions (Larson, 1977), although the literature lacks similar investigations of rhythm differences. The acts of conducting (Forsythe & Woods, 1983) and piano playing (Nápoles et al., 2017) while detecting errors add to cognitive load, given that the ability to detect errors decreased in those conditions. Firstly, a program of instruction was shown to improve rhythmic error detection in the choral rehearsal, indicating error detection is not a fixed ability but rather a skill that develops with instruction (Shaw, 1971). Most studies use the undergraduate music major population, whereas two used child populations of fifth and sixth graders (Thornton, 2008) or junior high students (Killian, 1991).

At the time of Davis's (2010) review, there were claims that error detection is a skill that requires its own practice—that it will not necessarily "emerge as a byproduct of practicing seemingly unrelated skills," furthermore suggesting, "a student's performance ability and prior experience may not correlate with their level of ED ability" (Davis, 2010, p. 43). Since that time, Stambaugh and Nichols (2020) established that experience such as instrument lessons, piano history, and age or number of years of enrollment and abilities such as interval identification skill were strongly related to melodic error detection scores. Interval identification was a strong predictor of melodic error dictation among those participants even after controlling for the number of semesters of enrollment and theory course level. Those participants completed tests of interval identification and error detection, which included 15 two-bar melodies composed of eight quarter notes. It is unknown whether there are rhythmic correlates to beat perception or possibly other variables such as melodic error detection, suggesting a gap in the literature.

Demographic characteristics and previous musical experiences have been variables of interest throughout error detection research. Due to inconsistencies in methodology between studies and opposing results, the impact of these variables still bears further inquiry. Age, sex, number of years of private study, conducting experience, ensemble experience (Brand & Burnsed, 1981; Grunow, 1980; Hansen, as cited in Taylor, 1963), degree level (Byo, 1993), and theory course grades (Stambaugh, 2016) were not significant predictors of error detection ability. Yet degree status (Byo, 1997), conducting experience (Cavitt, 2003; Gonzo, 1971), years of piano lessons (Nápoles et al., 2017), and aural skills course grades (Stambaugh, 2016) were found to have a positive relationship with error detection in other studies. Given our focus on rhythmic error detection, we were specifically interested in background experience with an emphasis on rhythm, such as participation in drumline, drum corps, or percussion ensemble. The purpose of this study was to explore the relationship between the basic component skill of beat perception and rhythmic error detection, as in the way that the component skill of interval identification was shown to predict melodic error detection. Our primary research question was how much variance in rhythmic error detection is explained by timekeeping ability, age, or percussion ensemble history? A secondary research question was whether rhythmic skills such as beat perception or rhythmic error detection are related to the skill of melodic error detection.

Method

To address the research questions, measures for beat perception, rhythmic error detection, and melodic error detection were required. We used two existing measures of beat perception/timekeeping and chose to develop a previously used test of three-part melodic error detection as single-line rhythm-only presentations. We included a previously used test of melodic error detection that was also highly correlated with interval identification skill.

Beat Perception

We chose to use two existing beat perception tests from the music psychology/education research literature because we could not find a precedent to guide us in the use of one test over the other in music education research. Furthermore, they assess the skill of beat perception through different listening tasks, as described in the following. Our results could show that one kind of listening task (test) was more related to rhythmic error detection than the other or that both tests had similar relationships to error detection. This information could help us interpret our results and potentially be useful for guiding future research in beat and rhythm.

The Beat Alignment Test (BAT) from Goldsmiths Music Sophistication Index version 1.0 (Müllensiefen et al., 2013) has 17 examples of ecologically valid music excerpts in rock, jazz, and classical styles. Tempos of the excerpts ranged from 85 to 165 bpm, and both duple and triple meters were included. While each 10–15 second exceprt plays, there is also a track of steady high-pitched beeps. The beeps are either on the beat, slightly ahead of or behind the beat (out of phase), or faster or slower than the beat. The beep alterations are 2%, 5%, or 17.5%. The listener must decide if the beeps are on the beat or not on the beat. This test was designed to be used with people with all levels of musical experience, and a recent replication confirmed it was appropriate for undergraduate music majors (Baker et al., 2020). Alpha coefficients from test and retest sessions were .87 and .92, and test-retest reliability were reported from d' scores (intraclass correlation coefficient = .63, r = .70, ρ = .72, all $p < .001$; Müllensiefen et al., 2014).

The second beat perception test was the Beat Finding and Interval Test (BFIT) from the Harvard Beat Assessment Test (H-BAT; Fujii & Schlaug, 2013). Participants listened to 32 examples of a woodblock sound playing 1 (+) 2 + 3 (+) (4) + 1 (+) 2 + 3 (+) (4) +, looped six times (counts in parentheses are silent). Each example was 10 to 15 seconds in duration. Examples began at 120 bpm and then either sped up or slowed down. Participants indicated whether the pattern sped up or slowed down. Fujii and Schlaug (2013) reported their results were consistent with previous research, finding a minimum threshold change of 5.6 bpm at 150 bpm (Kuhn, 1974: threshold of 6 bpm change at 150 bpm).

Rhythmic Error Detection

We adapted a previously designed three-part melodic error detection test of varying musical styles (Schlegel, 2010) by extrapolating single-line parts and removing pitch information. Williams (2021) suggested that focus of attention is a salient variable for multipart error detection, which reinforced our choice of monophonic rhythm excerpts presented on treble or bass clef staves for the purposes of this study. We designed rhythm foils and pilot tested them with college musicians ($N = 18$). Pass rates on the rhythmic error detection pilot test ranged from 0.33 to 1.00, with two participants getting a perfect score and the other participants achieving scores of 0.89 ($n = 5$), 0.78 ($n = 3$), 0 .75 ($n = 1$), 0.67 ($n = 2$), 0.44 ($n = 2$), and 0.33 ($n = 2$). Because two participants received a perfect score, we added new items of increased difficulty, including faster tempi and shorter note durations. The final test contained 15 items with foils consisting of various errors occurring on each beat in 4/4 bars of rhythmic stimuli, sometimes on the downbeat but also off the beat (see Figure S1 in the supplemental document included with the online version of this article). The stimuli were notated in Finale, and a separate file was created for inserting foils. This second file was used to generate audio files exported from Finale using the Grand Piano instrument timbre at varying tempi. During testing, one item appeared on screen at a time. Participants saw the correct notation and were able to choose how long they waited before listening to the foil sound file for one hearing. If they waited longer than 30 seconds, the researcher prompted them to start playing the sound file.

Melodic Error Detection

To test undergraduate students' melodic error detection ability, we used a test from previous research (Stambaugh & Nichols, 2020). That test was adapted from a measure of melodic error detection designed for junior high students (Killian, 1991). Our revision for undergraduate students proved to be a stable test of melodic error detection with an acceptable range of difficulty levels (see Figure S1 in the supplemental document included with the online version of this article). Each of the 15 items consisted of eight quarter-note pitches written in common time in two-bar durations. The pitch range was from C3 to F-sharp 4. These monophonic excerpts each contained one pitch error consisting of diatonic or chromatic foils based on the key center of F major, and they were played in Finale at 60 bpm with the Grand Piano timbre. Using Qualtrics software, the participants were presented with the melodic notation, chose when to start playing the sound file for one hearing only (Bounviri, 2019), and marked which pitch was played incorrectly or selected "no errors." The rhythmic and melodic tests were presented separately, and within each test, the item order was randomized.

Procedure

We tested participants individually in an office, with sessions lasting approximately 30 seconds. After completing the informed consent process, participants completed a demographic and music background survey using online Qualtrics software. Next, they completed the four tests (two beat perception tests, rhythmic error detection, and melodic error detection), presented in a random order. Participants used a laptop computer with external speakers, and all tests were presented through Qualtrics. Each test began with two practice items presented in the same format as the test items. During the practice items, we told participants they could adjust the volume of the computer speakers to their comfort level and that each item could be played only once. The researcher or research assistant monitored participants' activity to ensure they adhered to this protocol.

Participants

Musicians (*N* = 43; age: *M* = 19.8 years, *SD* = 1.4) recruited from two universities included freshmen (*n* = 12), sophomores (*n* = 13), juniors (*n* = 11), and seniors (*n* = 7) who were vocalists (*n* = 10) and instrumentalists (*n* = 33). They ranged in age from 18 to 23 years, and the sample comprised males (*n* = 19) and females (*n* = 24). All students were participating in a collegiate curricular music ensemble and majoring in music education (*n* = 32), music performance (*n* = 7), or "other" music major (*n* = 4). Because the purpose of the study included rhythm measures, we collected background data on previous participation in "drumline, drum corps, or percussion ensemble." Among participants indicating such experience (*n* = 9), the mean duration was 3.17 years (*SD* = 3.15). In addition, 26 participants indicated a history of piano lessons ranging 1 to 14 years, and among them, the mean was 3.46 years (*SD* = 3.73). All participants indicated years of lessons on their primary instrument (*M* = 5.6 years, *SD* = 3.3).

Test Instruments

An analysis of the test instruments indicated satisfactory difficulty and discrimination levels to support their use in the analyses described previously. We created a test of monophonic rhythmic error detection by adapting previously used three-part melodic stimuli in various styles plus new stimuli of increased rhythmic difficulty (Schlegel, 2010). The item difficulty of those 21 test items ranged .07 to .93, and test means ranged .33 to .90. For the melodic error detection test, we employed a shortened form of a previously used monophonic melodic error detection test using a piano timbre. The item difficulty of those 15 test items ranged .40 to .95, and test means ranged from 0.13 to 1.00. As a measure of internal consistency, we calculated Cronbach's α for rhythmic error detection ($\alpha = .73$) and pitch error detection ($\alpha = .79$). We interpreted these results to be acceptable in a measure of performance in this population (Allen & Yen, 2001). A histogram of the BAT results indicated that our participants performed

Table 1. Descriptive Statistics for Test Results in Rhythm Perception and Error Detection.

	BFIT	Goldsmiths	Rhythmic ED	Melodic ED
All participants	.60 (.07)	.85 (.12)	.69 (.16)	.61 (.23)
Age 18–19, *n* = 20	.58 (.04)	.85 (.14)	.72 (.14)	.61 (.28)
Age ≥ 20, *n* = 23	.62 (.08)	.85 (.10)	.66 (.17)	.61 (.18)

Note. These values are calculated after being transformed to a scale of 0 to 1 for comparison purposes. ED = error detection; BFIT = Beat Finding and Interval Test.

slightly higher than the norms from the original BAT study (here, mode = 85%; Müllensiefen et al., 2013, mode = 75%), with scores ranging from 0.53 to 1.00. Scores ranged 0.44 to 0.78 for the BFIT test; accuracy norms are not available for the BFIT (Fujii & Schlaug, 2013).

Results

The purpose of this study was to examine the relationship between two measures of beat perception and a test of monophonic rhythm error detection. Table 1 shows descriptive statistics for results of the four tests transformed to a scale of 0 to 1 for comparison purposes. Analyses indicated that these college musicians' abilities to detect rhythm errors were not significantly related to their ability to perceive beat alignment (Goldsmiths, $r[43] = .14$, $p > .05$) or tempo change (BFIT, $r[42] = –.18$, $p > .05$). Previous error detection research has found significant differences due to years of experience (e.g., DeCarbo, 1984). Therefore, we decided to divide participants into younger and older groups to compare their performances on each test. We found no significant correlation between age and pitch error detection ($r[43] = .11$ $p > .05$), rhythmic error detection ($r[43] = .02$, $p > .05$), or the Goldsmiths test ($r[43] = .02$, $p > .05$). Performance on the BFIT test was weakly correlated with age, $r(42) = .32$, $p = .042$. After testing assumptions, a multivariate analysis of covariance using test completion order as covariate did not indicate the presence of order effects ($p > .05$).

We conducted a multiple regression analysis to examine the extent to which beat perception ability served as a predictor of rhythmic error detection alongside a background variable representing musical experience. Upon testing for the assumptions of multiple regression analysis (Tabachnick & Fidell, 2007), visual inspections of scatterplots suggested linear relationships, and normality plots of standardized residuals indicated normally distributed errors and homoscedasticity. P-P plots provided evidence of small violations of homoscedasticity for the BFIT test. We chose to proceed without performing a transformation because these violations were minor (Miksza & Elpus, 2018). Standardized univariate skewness and kurtosis values fell between the range of ±1.0 *SD* and were nonsignificant ($p > .05$), suggesting univariate normality. Durbin-Watson test results indicated a value of 1.747, signifying no concerns of autocorrelation. Tolerance statistics and variance inflation factors were also within

Table 2. Hierarchical Regression Predicting Rhythmic Error Detection Scores.

R^2	Variable	*B*	*SE* β	β
.232	Constant	11.334	6.226	
	BFIT	–0.104	0.233	–0.067
	Goldsmiths	0.021	0.252	0.013
	Years of lessons	0.281	0.148	0.288
	Melodic error detection	0.366*	0.144	0.395

Note. BFIT = Beat Finding and Interval Test.
*$p < .05$.

recommended ranges (>0.5 and <10.0, respectively), indicating the absence of multicollinearity.

The dependent variable was rhythmic error detection, and the following independent variables were entered: the two tests of beat perception, the test of melodic error detection, and years of lessons. Years of lessons was included as a covariate representing musical experience. Results indicated a significant model in which pitch error detection was the only significant predictor ($p = .015$), explaining 15% of the variance in rhythmic error detection scores, $\Delta R^2 = .149$, $F(4, 37) = 2.794$, $p = .040$. This model follows the convention for number of variables per the sample size ($k \times 7$). Pearson correlations among all variables are shown in Table S1 in supplemental document included with the online version of this article, and results of the regression analysis are summarized in Table 2.

Finally, we wished to explore whether a requisite rhythm error detection test ability was related to high performance on other tests. We divided the participants into three near-equal groups of low ($n = 13$), medium ($n = 16$), and high ($n = 13$) rhythmic error detection ability. We tested the assumptions for multivariate analysis of variance (MANOVA) including visual inspection of linearity in scatterplots between dependent variables and the low, medium, and high groups; Mahalanobis distances for absence of multivariate outliers; and the Box's M test for equality of variances ($p = .740$). We employed a MANOVA to compare performance on the test scores transformed to a $0 \leq$ to ≥ 1 scale as the dependent variables and with rhythm error detection grouping as the between-subject variable, $F(6, 74) = 12.74$, $p < .001$; Wilk's $\Lambda = .242$, partial $\eta^2 = .51$. Post hoc comparisons did not indicate significant differences for rhythm performance groupings on the tests for melodic error detection or the two beat perception tests ($p > .05$; Figure 1).

Discussion

The purpose of this study was to examine the relationships among rhythmic error detection, beat perception, and melodic error detection. Previous results indicated a strong relationship between the basic skill of interval identification and the more

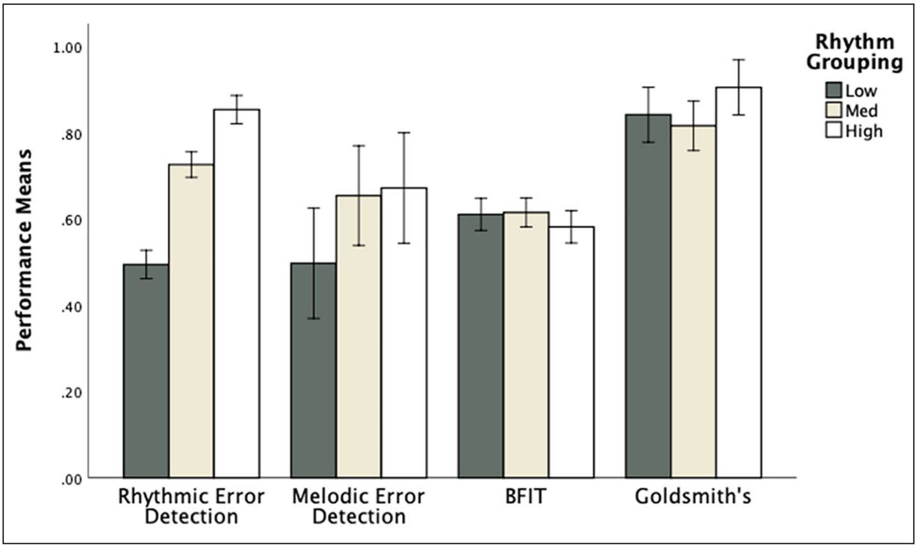

Figure 1. Performance of low, medium, and high scorers by the rhythmic error detection test.
Note. Transformed to a scale of 0 to 1. Error bars indicated 95% confidence interval. BFIT = tempo change test (Beat Finding and Interval Test); Goldsmiths = beat alignment test.

complex skill of monophonic melodic error detection (Stambaugh & Nichols, 2020), but results of the present study did not indicate a similar relationship, the basic skill of beat perception was not highly correlated to the more complex skill of rhythmic error detection. That is, the relationship of interval identification and melodic error detection does not have a corollary in the relationship of beat alignment or tempo change identification to rhythmic error detection.

A unique contribution of this study is the use of beat perception tests from cognition research in the context of applied music educator skills. Our musicians' mean score on the Goldsmiths BAT was higher than their mean score on the BFIT. The Goldsmiths task used real-world music examples with multiple instruments and polyphonic textures. The music contained subtle metrical and volume accents that could help a listener find the beat (Bouwer et al., 2018; Drake et al., 1999; London, 2011). In addition, familiar surface characteristics of rock and jazz timbres, rhythms, and textures could have prompted participants to want to move to the beat, activating an embodied music cognition framework (Cox, 2016; Fujii & Schlaug, 2013; although we specifically asked participants to not move to the beat while completing the listening tests). On the contrary, the BFIT tempo change test used a synthesized woodblock sound that contained no additional metrical or volume clues. Therefore, it could be argued that the BFIT task was more challenging to participants than the Goldsmiths task. This difficulty could account for the finding that older students scored higher than younger students on the BFIT and for the significant correlation between age and BFIT scores.

Likewise, Farley (2014) found that college instrumentalists who kept a mental subdivision were more accurate rhythm sight readers than instrumentalists who did not keep a subdivision. Older students in the current study may have been more capable of keeping a mental subdivision, thereby improving their scores on the BFIT. Future research could examine if keeping an internal subdivision is related to success on the Goldsmiths and BFIT tests. In addition, future research with early career teachers could further illuminate developmental aspects of beat perception and error detection.

Our findings indicated a limited relationship between scores on the beat perception tests and scores on the rhythm error detection test. The data do not directly indicate that higher scores on beat alignment detection or beat change detection are required for detecting rhythm errors. Although individuals varied in their ability to indicate beat alignment (Goldsmiths) and beat change (BFIT), all participants still demonstrated some ability to detect errors (test means ranged from .33 to .90). Therefore, we suggest other correlates to rhythm error detection may exist, such as rhythm performance or the ability to identify or notate rhythm patterns. Thus, our conclusion is that music majors possess a minimum basic skill for identifying tempi change and beat alignment that does not result in a strong correlation between those skills and the ability to detect errors in monophonic rhythms. According to previous research, the correlates in our study or any potential untested correlates may be expected to vary based on difficulty of the error detection task, including the number of parts or the use of polyphonic texture (Byo, 1993, 1997).

Of course, scores on the melodic error detection test were predictive of scores on the rhythmic error detection test. This result is important because previous findings on sight-reading skill suggest a limited relationship between pitch and rhythm accuracy (Byo, 1992; Mishra, 2016; Russell, 2019). Age was a less important factor in predicting rhythm errors in the present study than it was for pitch errors in a previous study (Stambaugh & Nichols, 2020). Given a baseline beat perception ability among these college musicians, melodic error detection is a better predictor of rhythmic error detection than measures of beat perception. We use this finding to suggest that there exists certain component skills of error detection, which is a more advanced skill. Error detection requires ability in multiple component skills such as maintaining a tonal center, keeping a beat, or keeping a steady beat to track music notation across a page.

The current data and previous results (Stambaugh & Nichols, 2020) indicate that melodic error detection may be more strongly related to age than rhythm error detection is related to age. The identification of pitch errors and pitch relationships may develop with age, experience, or training in a different way than the ability to detect errors in rhythms (Byo, 1997) and perhaps more similarly to sight-reading development. Whether individuals were more foiled by fast tempi or by shorter note durations was not a main research question and cannot be addressed by the data, in which participants indicated the measure number containing an error. Possibly, these foils influenced performance differentially among the participants, but a longer test would be required to establish rhythm difficulty and discrimination as it pertains to tempo (BFIT) or pulse alignment (Goldsmiths).

Participants who performed in a drumline or other percussion ensemble did not have superior beat perception or error detection skills compared to participants without percussion experience. We included percussion experience as a covariate because we theorized it could be related to beat perception or rhythmic error detection ability (per Bouwer et al., 2016). College musicians with percussion experience may indicate typical beat perception and error detection skills compared to musicians without percussion experience, or the tasks in this study may not have required an unusually high level of beat competence.

When participants were grouped by rhythmic error detection ability, we found no significant differences among the groups on the other three tests. However, we extend that result with caution, noting that any potential differences would be expected to vary based on task type (perception vs. performance) and task difficulty levels. Again, a certain level of rhythm (and pitch) skill exists in the college musician population, who are generally admitted to collegiate study by audition. Possibly, an individual must possess certain rhythm skills to score higher on melodic error detection, for example. Beyond a medium threshold of difficulty, it may not matter how much more accurately an individual performs rhythmic error detection to score higher on other tests. We note that our test of melodic error detection did not include rhythm features since the stimuli consisted only of quarter note durations.

Implications

Our participants earned a range of scores on the tests, but it is possible there are music majors who lack musicianship skills commensurate with those who elected to participate in this research. Possibly, these effects are absent or different in participants with low beat perception or low error detection—whether rhythmic or melodic. Teacher educators cannot presume these two modes of error detection are correlated for all students. Presently, we recommend that rhythmic versus melodic error detection be approached with differences in musician experience in mind, although our data suggest percussion ensemble experience was not a significant predictor for performance on our tests.

Furthermore, we continue to think of rhythmic and melodic error detection as separate skills, albeit related. We suggest preservice teachers may begin developing error detection skills in early music education courses or field experiences by listening to short items that address only interval identification, or monophonic melodic error detection, or rhythmic error detection. Yet there may be individuals for whom melodic and rhythmic error detection is less related (see Figure 1). In addition, our tests for both types of error detection (see Supplementary Materials) may be useful in the classroom given their acceptable internal consistencies and in the case of music majors, a general absence of floor or ceiling effects.

Conclusion

The predictive ability of melodic error detection on rhythmic error detection is a novel finding deserving of future research. We expect that there exist other correlates to error detection that are as of yet undiscovered in the research literature. Although performance may be expected to vary by age, it can also be expected to vary by experience in music coursework in middle and high school and college. The role of music coursework and musical experiences such as percussion ensembles or even jazz (e.g., Nichols et al., 2018) can be explored in even more nuanced ways as teachers and researchers design curricula to expand on all the requisite skills for music-making and music leadership. Programs for error detection training exist for teachers and professors, who might explore how and whether melodic and rhythmic error detections skills develop concurrently across a course or across the collegiate years. Finally, music majors self-select to prepare for careers in music performance and education. These factors may vary in the general population of college students for which the existing rhythm perception tests have been piloted and tested. Given that interval identification skill has been highly correlated with detecting pitch errors and that melodic error detection was related to detecting rhythm errors in the present study, future research might explore whether component skills like interval identification, beat perception, or beat production are related to an array of more complex skills including and beyond rhythmic error detection.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Bryan E. Nichols https://orcid.org/0000-0002-8970-3284
Laura A. Stambaugh https://orcid.org/0000-0002-7459-5890

Supplemental Material

Figure S1 and Table S1 are available in the online version of the article at https://doi.org/10.1177/00224294211032160.

References

Allen, M. J., & Yen, W. M. (2001). *Introduction to measurement theory*. Waveland Press.

Baker, D. J., Ventura, J., Calamia, M., Shanahan, D., & Elliott, E. M. (2020). Examining musical sophistication: A replication and theoretical commentary on the Goldsmiths Musical Sophistication Index. *Musicae Scientiae*, *24*(4), 411–429. https://doi.org/10.1177/1029864918811879

Bouwer, F. L., Burgoyne, J. A., Odijk, D., Honing, H., & Grahn, J. A. (2016). What makes a rhythm complex? The influence of musical training and accent type on beat perception. *PLoS ONE*, *13*(1), Article e0190322. https://doi.org/10.1371/journal.pone.0190322

Bouwer, F. L., Burgoyne, J. A., Odijk, D., Honing, H., & Grahn, J. A. (2018). What makes a rhythm complex? The influence of musical training and accent type on beat perception. *PLoS ONE*, *13*(1), 1–26.

Brand, M., & Burnsed, V. (1981). Music abilities and experiences as predictors of error-detection skill. *Journal of Research in Music Education*, *29*(2), 91–96. https://doi.org/10.2307/3345017

Buonviri, N. O. (2019). Effects of silence, sound, and singing on melodic dictation accuracy. *Journal of Research in Music Education*, *66*, 365–374. https://doi.org/10.1177/0022429418801333

Byo, J. L. (1992). Effects of barlines, pitch, and meter on musicians' rhythm reading performance. *Journal of Band Research*, *27*(2), 34–44.

Byo, J. L. (1993). The influence of textural and timbral factors on the ability of music majors to detect performance errors. *Journal of Research in Music Education*, *41*(2), 156–167. https://doi.org/10.2307/3345405

Byo, J. L. (1997). The effects of texture and number of parts on the ability of music majors to detect performance errors. *Journal of Research in Music Education*, *45*(1), 51–66. https://doi.org/10.2307/3345465

Cavitt, M. E. (2003). A descriptive analysis of error correction in instrumental music rehearsals. *Journal of Research in Music Education*, *51*(3), 218–230. https://doi.org/10.1016/B978-012672690-9/50010-X

Clark, T., & Williamon, A. (2011). Imagining the music: Methods for assessing musical imagery ability. *Psychology of Music*, *40*(4), 471–493. https://doi.org/10.1177/0305735611401126

Cox, A. (2016). *Music and embodied cognition: Listening, moving, feeling, and thinking*. Indiana University Press.

Davis, S. (2010). Error detection in the aural skills class: Research and pedagogy. *Journal of Music Theory Pedagogy*, *24*, 37–67.

DeCarbo, N. (1984). The effect of years of teaching experience and major performance instrument on error detection scores of instrumental music teachers. *Contributions to Music Education*, *11*, 28–32.

Drake, C., Gros, L., & Penel, A. (1999). How fast is that music? The relation between physical and perceived tempo. In S. W. Yi (Ed.), *Music, mind, and science* (pp. 190–203). Seoul National University.

Duke, R. A., Geringer, J. M., & Madsen, C. K. (1991). Performance of perceived beat in relation to age and music training. *Journal of Research in Music Education*, *39*(1), 35–45. https://doi.org/10.2307/3344607

Farley, A. L. P. (2014). *The relationship between musicians' internal pulse and rhythmic sight-reading* [Unpublished doctoral dissertation]. University of Washington.

Forsythe, J. L., & Woods, J. R. (1983). The effects of conducting on the error detection ability of undergraduate and graduate instrumental conductors. *Contributions to Music Education*, *10*, 27–32. https://doi.org/10.2307/24127375

Fujii, S., & Schlaug, G. (2013). The Harvard Beat Assessment Test (H-BAT): A battery for assessing beat perception and production and their dissociation. *Frontiers in Human Neuroscience*, *7*, Article 771. https://doi.org/10.3389/fnhum.2013.00771

Gonzo, C. L. (1971). An analysis of factors related to choral teachers' ability to detect pitch errors while reading the score. *Journal of Research in Music Education*, *19*(3), 259–271. https://doi.org/10.2307/3343762

Groulx, T. (2013). The influence of tonal and atonal contexts on error detection accuracy. *Journal of Research in Music Education*, *61*(2), 233–243. https://doi.org/10.1177/0022429413485602

Grunow, R. F. (1980). *An investigation of the relative effectiveness of four modes of score preparation on visual-aural discrimination skills development* [Unpublished dissertation]. University of Michigan.

Henry, M. J., & Herrmann, B. (2014). Low-frequency neural oscillations support dynamic attending in temporal context. *Timing and Time Perception*, *2*(1), 62–86. https://doi.org/10.1163/22134468-00002011

Jones, M. R. (1976). Time our lost dimension: Toward a new theory of perception, attention, and memory. *Psychological Review*, *83*(5), 323–355. https://doi.org/10.1037/0033-295x.83.5.323

Killian, J. (1991). The relationship between sightsinging accuracy and error detection in junior high singers. *Journal of Research in Music Education*, *39*(3), 216–224. https://doi.org/10.2307/3344721

Kuhn, T. L. (1974). Discrimination of modulated beat tempo by professional musicians. *Journal of Research in Music Education*, *22*(4), 270–277. https://doi.org/10.2307/3344892

Kung, H.-N. (2017). *Cultural influence on the perception and cognition of musical pulse and meter* [Unpublished doctoral dissertation]. The Ohio State University.

Larson, R. C. (1997). Relationships between melodic error detection, melodic dictation, and melodic sightsinging. *Journal of Research in Music Education*, *25*(4), 264–271. https://doi.org/10.2307/3345267

London, J. (2011). Tactus ≠ tempo: Some dissociations between attentional focus, motor behavior, and tempo judgment. *Empirical Musicology Review*, *6*(1), 43–55. https://doi.org/10.18061/1811/49761

Matthews, T. E., Thibodeau, J. N. L., Gunther, B. P., & Penhune, V. B. (2016). The impact of instrument-specific musical training on rhythm perception and production. *Frontiers in Psychology*, *7*, Article 69. https://doi.org/10.3389/fpsyg.2016.00069

McAuley, J. D. (2010). Tempo and rhythm. In M. R. Jones, R. Fay, & A. Popper (Eds.), *Music perception. Springer handbook of auditory research* (pp. 165–199). Springer. https://doi.org/10.1093/oxfordhb/9780199233557.013.0010

Miksza, P., & Elpus, K. (2018). *Design and analysis for quantitative research in music education*. Oxford University Press.

Mishra, J. (2016). Rhythmic and melodic sight reading interventions: Two meta-analyses. *Psychology of Music*, *44*(5), 1082–1094. https://doi.org/10.1177/0305735615610925

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS ONE*, *9*(2), Article e89642. https://doi.org/10.1371/journal.pone.0089642

Müllensiefen, D., Gingras, B., Stewart, L., & Musil, J. J. (2013). *Goldsmiths Musical Sophistication Index (Gold-MSI) v1.0 technical report and documentation revision 0.3. Technical Report*. https://www.gold.ac.uk/music-mind-brain/gold-msi/

Nápoles, J., Babb, S., Bowers, J., Hankle, S., & Zrust, A. (2017). The effect of piano playing on preservice teachers' ability to detect errors in a choral score. *Journal of Music Teacher Education*, *26*(2), 149–162. https://doi.org/10.1177/1057083716639724

Nichols, B. E., & Springer, D. G. (2021). Interval identification predicts success in melodic dictation. *Journal of Research in Music Education*. Advance online publication. https://doi.org/10.1177/00224294211011962

Nichols, B. E., Wöllner, C., & Halpern, A. (2018). Score one for jazz: Working memory in jazz and classical musicians. *Psychomusicology: Music, Mind, and Brain*, *28*(2), 101–107. https://doi.org/10.1037/pmu0000211

Potter, D. D., Fenwick, M., Abecasis, D., & Brochard, R. (2009). Perceiving rhythm where none exists: Event-related potential (ERP) correlates of subjective accenting. *Cortex*, *45*(1), 103–109. https://doi.org/10.1016/j.cortex.2008.01.004

Povel, D.-J., & Essens, P. J. (1985). Perception of temporal patterns. *Music Perception*, *2*(4), 411–440. https://doi.org/10.2307/40285311

Russell, C. R. (2019). Effects of pitch and rhythm priming tasks on accuracy and fluency during sight-reading. *Journal of Research in Music Education*, *67*(3), 252–269. https://doi.org/10.1177/0022429419851112

Schlegel, A. (2010). *The effect of directed attention score study procedures on music majors' error detection in three-part instrumental music* [Doctoral dissertation, Louisiana State University]. https://digitalcommons.lsu.edu/gradschool_dissertations/1215

Shaw, T. (1971). A program to improve choral conducting students' ability to detect rhythmic errors in choral rehearsal. *Dissertation Abstracts International*, *32*(12), 7034A.

Sheldon, D. (2004). Effects of multiple listenings on error-detection acuity in multivoice, multitimbral musical examples. *Journal of Research in Music Education*, *52*(2), 102–115. https://doi.org/10.2307/3345433

Stambaugh, L. (2016). Differences in error detection skills by band and choral preservice teachers. *Journal of Research in Music Education*, *25*(2), 25–36. https://doi.org/10.1177/1057083714558421

Stambaugh, L., & Nichols, B. E. (2020). The relationships among interval identification, pitch error detection, and stimulus timbre by preservice teachers. *Journal of Research in Music Education*, *67*(4), 465–480. https://doi.org/10.1177/0022429419885931

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics*. Pearson.

Taylor, C. C. (1963). Critique of a study of the ability of musicians to detect melodic and harmonic errors in the performance of choral music while inspecting the score. *Bulletin of the Council for Research in Music Education*, *1*(1), 45–49.

Thompson, W. F., & Schellenberg, E. G. (2002). Cognition constraints on music listening. In R. Colwell & C. Richardson (Eds.), *The new handbook of research on music teaching and learning* (pp. 461–468). Oxford University Press.

Thornton, L. C. (2008). The effect of grade, experience, and listening condition on the melodic error detection of fifth- and sixth-grade woodwind students. *Update: Applications of Research in Music Education*, *26*(2), 4–10. https://doi.org/10.1177/8755123308317612

van Noorden, L., & Moelants, D. (1999). Resonance in the perception of musical pulse. *Journal of New Music Research*, *28*(1), 43–66. https://doi.org/10.1076/jnmr.28.1.43.3122

Williams, M. (2021). The effect of focus of attention on error detection ability. *Journal of Research in Music Education*. Advance online publication. http://doi.org/10.1177/0022429421997449

Wöllner, C., & Halpern, A. (2016). Attentional flexibility and memory capacity in conductors and pianists. *Attention, Perception, & Psychophysics*, *78*, 198–208. https://doi.org/10.3758/s13414-015-0989-z

Author Biographies

Bryan Nichols is an assistant professor of music at Penn State University (University Park). His research interests include singing accuracy and participation and musicianship skills.

Laura Stambaugh is a professor/head of music education at Georgia Southern University. Her research interests are music motor learning, error detection, and music cognition.

Submitted November 16, 2020; accepted June 9, 2021.