Testing a Model of Jazz Rhythm: Validating a Microstructural Swing Paradigm

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UNIVERSITY OF MIAMI

TESTING A MODEL OF JAZZ RHYTHM: VALIDATING A MICROSTRUCTURAL SWING PARADIGM

By

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TESTING A MODEL OF JAZZ RHYTHM: VALIDATING A MICROSTRUCTURAL SWING PARADIGM

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The purpose of this study was to create and test two hypothesized models for swing in jazz performance. In order to estimate the hypothesized fully latent variable Swing model, eighth note samples \( N = 815 \) from five improvised solos by Chris Potter were analyzed. Three first order factors were identified and examined that were hypothesized to define swing: eighth note duration, beat placement, and note dynamics. These three factors were measured with accuracy beyond a thousandth of a millisecond. Nine second order factors were identified and grouped into soloist-controlled variables and non-soloist controlled variables: metrical beat placement, melodic character, intervals, articulation, range, underlying harmony, tempo, bass beat placement, and drummer beat placement. The methodology of the measurement system and data collection procedures prescribed in this research study was found to contain limitations that prevented the administration of a proper statistical analysis for an estimation of the proposed models. Results of the simultaneous multiple regression analysis revealed that metrical beat placement, melodic character preceding, melodic character succeeding, interval preceding, interval succeeding, articulation, range, underlying harmony, and tempo combined to account for 6.7% of the variance in eighth note duration \( (N = 394) \), 

\[
R^2 = .067, F_{(8,385)} = 3.48, p = .001, \text{ with interval preceding } (\beta = -.162, t_{(-3.00)}, p = .002), \text{ and interval succeeding } (\beta = -.16, t_{(-3.20)}, p = .002) \text{ having a statistically significant} 
\]
effect. Metrical beat placement, melodic character preceding, melodic character succeeding, interval preceding, interval succeeding, articulation, range, underlying harmony, and tempo combined to account for 22.3% of the variance in note dynamics ($N = 231$) with tempo ($\beta = .408, t(6.427), p < .001$) having a statistically significant effect on note dynamics. The omnibus test for beat placement ($N = 99$) was found to be statistically insignificant, $R^2 = .052, F(8,90), p = .760$. 
Dedicated to my wife, Monica, for her love, support, and encouragement
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CHAPTER ONE

Statement of the Problem

From the earliest critical writings and discussions about jazz, swing has been identified as one of the most central and fundamental elements of jazz rhythm (Berliner, 1994; Collier & Collier, 1996; Friberg & Sundström, 2002; Liebman, 1997; Reeves, 1997; Schuller, 1968). More specifically, the element of swing is what distinguishes jazz from all other genres of music (Gridley, 1988). However, despite its role as a central element in jazz performance, educators and performers have difficulty defining swing in concrete terms (Liebman, 1997). This lack of definitional clarity inhibits educators from developing informed pedagogical strategies for teaching the most important element of jazz rhythm, swing.

One approach that can potentially aid educators and performers to more clearly define and understand the function of swing in jazz rhythm is to construct and statistically validate a theoretical model of jazz rhythm that incorporates the important factors affecting the overall function of swing. Models play a role in clarifying complex processes through visual representation. They enhance our ability to speculate about processes, consider alternatives, and develop hypotheses (Edwards, 1992, p. 39). In addition, models serve to bring order, manageability, and comprehension to complex relationships.
In the field of music education, models have been used to more clearly understand the processes of musical affect (Asmus, 1980), music performance assessment (Wrigley, 2005), sight-reading (Kopiez & Lee, 2008), jazz improvisation achievement (Ciorba, 2006), and music performance assessment (Russell, 2010). The building of a hypothetical model to explain the constructs of swing may lead to an improved understanding of its overall role in jazz. Specifically, by empirically substantiating what factors define and affect swing, a more complete definition of swing can be revealed. Such a definition would provide the foundation for a systematic, pedagogical method for teaching swing.

**Attempts to Define Swing**

Etymological investigations into the term “swing” find it to be fundamentally undefinable: “Though basic to the perception and performance of jazz, swing has resisted concise definition or description” (Johnson, 2001). Jazz critics have long sought to identify the constructs of swing through speculative commentary related to time-feel in musical performances:

… progressive retarding and acceleration. (Patterson, 1917, pp. 28-29)

Jazzing up a piece is to start (a note) a little ahead of the beat. (Thomson, 1925, p. 54)

… playing rhythms variously suspended around the beat. (Hobson, 1935, p. 30)

… the gifted player tends to place his notes a little away from the beat; he anticipates or lags behind while the real beat tries, like a magnet, to draw the brass note [of melody instruments back] to its own center of force. (Blesh, 1946, p. 164)

… the rhythmic valuations of notes may be lengthened or shortened according to a regular scheme… as long as a steady beat remains implicit or explicit. (Ulanov, 1952, p. 7)
… the accurate timing of a note in its proper place. (Schuller, 1968, p. 7)

… breaking away from the time framework of the ground beat to produce lines that are essentially rhythmically free. (Collier, 1978, p. 24)

… the melody remains in the vicinity of the beat but floats on either side, without restriction. (Kernfeld, 1995, pp. 24-25)

Although often ambiguous in nature, these examples and much of early jazz criticism alluded to the notion of performers’ rhythmic flexibility in defining swing.

**Defining the mechanical constructs of swing.** The concept of rhythmic flexibility, or the performer’s interpretation of sequential rhythmic figures against the underlying pulse, has often been conceptualized through metaphoric illustrations.

According to Charles Mingus (1995):

> I use the term “rotary perception.” If you get a mental picture of the beat existing within a circle you’re more free to improvise. People used to think the notes had to fall on the centre of the beats in the bar at intervals like a metronome, with three or four men in the rhythm section accenting the same pulse. That’s like parade music or dance music. But imagine a circle surrounding each beat- each guy can play his notes anywhere in that circle and it gives him a feeling he has more space. The notes fall anywhere inside the circle but the original feeling for the beat doesn’t change. (pp. 124-125)

In addition, Benward and Wildman (1984) explain:

> A beat can either be wide or narrow. For example, although each beat occurs as a “point” in time, try to envision the difference between the “point” made by an ultrafine-line pen and a magic marker. The ultrafine-line pen demonstrates the center of a beat, while the magic marker widens the possibilities, allowing a loose, swinging, personal approach to time on many different structural levels. A wide-beat concept is not just a haphazard reaction, however; it is idiomatic to the jazz style. (p. 127)
Here, Mingus, Benward, and Wildman are referring to the placement of the beat relative to the perceptual pulse. In addition to beat placement, rhythmic flexibility can be further reflected through the durational values of a performer’s eighth notes.

This is a very subtle aspect of jazz phrasing which specifically involves the length of space between the downbeat and upbeat of two eighth notes. The length of... the triplet... depending upon how one conceptualizes it, can be varied mathematically and microscopically to reflect a whole palette of proportions between the two divisions of the beat. Some musicians have a long duration of the downbeat than others, for example the ride beat cymbal pattern of drummer Elvin Jones. On the other hand, the great Tony Williams had an almost opposite proportion in his ride beat... Each artist brings his own way of feeling this division to the music. This variable has a large effect upon beat placement. (Liebman, 2003, p. 23)

Human music performances are always characterized by marked deviations from mechanical, rhythmic regularity (Gabrielsson, 1993). These deviations occur at several levels: each single note, at the beat level, at the half-measure level, at the measure level, and so on. Moreover, these patterns of deviations vary among genres of music and individual performers (Bengtsson & Gabrielsson, 1980; Gabrielsson, Bengtsson, & Gabrielsson, 1983).

Another characteristic of jazz swing style is the notion of “democratization of rhythmic values” (Schuller, 1968, p. 6). The democratization of rhythmic values refers to the dynamics with which specific notes are performed. In the jazz genre, Schuller (1968) explains:

… [the] so-called weak beats (or weak parts of rhythmic units) are not underplayed as in “classical” music. Instead, they are brought up to the level of strong beats, and very often even emphasized beyond the strong beat. The jazz musician does this not only by maintaining an equality of dynamics among “weak” and “strong” elements, but also by preserving the full sonority of notes, even though they may happen to fall on weak parts of the measure. (p. 8)
The most tangible and perceptually obvious examples of democratization of rhythmic values in the jazz style are backbeat development (emphasis of beat two and beat four in a 4/4 metered pulse) and the utilization of syncopation (the placement of dynamic accents on off-beats). Regarding backbeat emphasis, Liebman (2003) states: “Every jazz musician knows that ‘two’ and ‘four’ are the swinging beats and in fact it is the four that really swings, while the upbeat of four swings even more” (p. 21). A performer’s unique flexibility in rhythm, as evidenced by beat placement and eighth note duration, and beat emphasis as evidenced through the democratization of rhythmic values, serves as a tool for musical expression and accounts for the rich variety of nuance found in jazz performance. Figure 1.1 shows the relationships of the mechanical constructs of swing that function as musical expression:

![Diagram of Musical Expression in Jazz Rhythm]

**Figure 1.1.** Constructs of musical expression as displayed through jazz rhythm.
The empirical testing of the three swing constructs, note dynamics, beat placement, and eighth note duration, will shed light on their complexities in swing rhythm. It must be remembered that the totality of the literature still does not provide a complete definition of swing. The data that defines these three constructs is extremely complex, yet one-sided. These constructs characterize various facets of the concept of swing. However, they do not provide a complete picture of the phenomenon. The existing empirical data does not reveal statistically significant information regarding their intricate interrelationships. The combination of the data gleaned from the soloist, the data gleaned from each participating ensemble member, and the data gleaned from their interaction adds further complexity to an already intricate paradigm. A unified vision is needed to more completely conceptualize the jazz swing paradigm. Specifically, the empirical examination of the interrelationships between the predictors of note dynamics, beat placement, and eighth note duration as well as an examination of the musical factors that influence these constructs may provide a more complete definition of the function of swing. By empirically substantiating what is “consistent” within these constructs, a more complete definition of swing should be revealed.

**Need for the Study**

Jerome Bruner’s (1960) theory of the role of structure in learning and teaching outlines the importance of structure as a fundamental concept to understanding:

The teaching and learning of structure, rather than simply the mastery of facts and techniques, is at the center of the classic problem of transfer... If earlier learning is to render later learning easier, it must do so by providing a general picture in terms of which the relations between things encountered earlier and later are made as clear as possible. (p. 12)
Bruner’s theoretical framework for learning explains that a learner selects and transforms information, constructs hypotheses, and makes decisions based upon a cognitive structure. In addition, consideration is needed for the ways in which a body of knowledge can be structured in order to achieve and optimize student understanding. Instruction must be organized in order for the student to easily grasp information and designed to facilitate extrapolation of information and/or fill in the gaps with new information.

One of the most fundamental elements in jazz performance is swing rhythm. However, it is one of the least discussed elements in jazz education because of its elusive nature. Problems exist due to the difficulty of describing it in concrete terms (Lawn, 1981; Liebman, 1997). Within the fundamental structure of jazz rhythm, it seems that there are three major constructs that underscore the operation of swing rhythm: (a) note duration of consecutive eighth notes, (b) placement of the beat in relation to the perceived pulse, and (c) note dynamics.

Musicological and psychological research literature pertaining to microstructural rhythm in jazz performance has unveiled numerous factors that affect these three constructs of swing. These factors include eighth note duration (Benadon, 2006; Busse, 2002; Cholakis & Parsons, 1995; Collier & Collier, 2002; Poval, 1977; Rose, 1989), swing-ratio (Benadon, 2006; Biles, 1994; Cholakis & Parsons, 1995; Collier & Collier, 2002; Ellis, 1991; Friberg & Sundström, 2002; Reinholdsson, 1987; Rose, 1989), phrase structure (Benadon, 2006; Collier & Collier, 1994; Rose, 1989), placement of the beat (Benadon, 2006; Busse, 1997; Collier & Collier, 1996; Reinholdson, 1987; Rose, 1989), rhythmic flexibility (Busse, 2002; Pressing, 1987;
Reinoldsson 1987), musical instrument (Rose, 1989), tempo (Collier & Collier, 1994; Ellis, 1991; Friedberg & Sundström, 2002), harmonic character (Benadon, 2006), note attack velocity, (Busse, 2002) and note placement (Busse, 2002). The importance of these factors lies in their direct influence upon the fundamental structure of jazz swing rhythm.

Figure 1.2 demonstrates the hierarchical nature of the elements of jazz performance and jazz rhythm. The foreground consists of the most surface elements of jazz performance: melody, harmony, and rhythm. The middleground consists of the musical factors that may influence swing rhythm but are fundamental to the elements of jazz performance; specifically, rhythm in jazz performance. The background consists of the combination of microstructural elements that form the constructs of jazz swing rhythm. If the hierarchy is viewed from a bottom-up perspective, the microstructural constructs form the foundation and operational basis of swing. Without this foundation, jazz performance employing the use of swing rhythm cannot exist.

![Diagram](image_url)  
*Figure 1.2. Fundamental structure of jazz performance.*
The data gleaned from these research studies provides valuable insight into the operational functioning of jazz rhythm. However, the empirical output does not offer statistical significance. In addition, the data does not address the relationships of eighth note duration, beat placement, and note dynamics or their combined effects on swing rhythm. The measured deviations from mechanical regularity are offered at face value with little evidence that the results are consistent across multiple performances. More importantly, the sample sizes used in these studies are not large enough to offer consistency in the reported data. The topic of swing has yet to be discussed, defined, or empirically tested.

A need exists to (a) reexamine and organize the mechanical constructs of swing rhythm, (b) explore how the constructs function dependently and independently of each other, (c) investigate what musical factors affect those constructs, and (d) study how the relationship between these constructs and factors influence our perception of what “swing” is. Specifically, a measure of swing is needed in order to establish a fundamental structure for teaching jazz rhythm. Once a structural foundation of swing is successfully constructed and statistically validated, it can serve as a foundation to the development of a pedagogical model for teaching jazz rhythm.

The aim of this study was to further develop a fundamental understanding of the factors that affect swing rhythm in jazz performance. The understanding of the microstructural elements of jazz swing is fundamental to the learning and understanding of jazz rhythm. More importantly, it provides a fundamental understanding of performance practice in the jazz idiom. In addition, the empirical
testing of jazz rhythm may provide valuable insight into identifying, diagnosing, and prescribing solutions to problems pertaining jazz phrasing and time-feel.

**Theory of Swing**

Research into the elements of swing in jazz performance has provided strong evidence that musical structure occurs on the microrhythmic level. The data gleaned from empirical measurements of eighth note values, beat placement, and note dynamics suggests that these three exogenous variables contribute to the overall structure and functioning of swing rhythm. Each of these variables contains a unique variance and shared variance among themselves. In this study, the shared variance among these constructs is what defines swing. Figure 1.3 demonstrates the derivation of swing within the constructs of eighth note duration, beat placement, and note dynamics.

![Diagram](Image)

*Figure 1.3. The relationship of swing to its three constructs: Eighth-note duration, beat placement, and note dynamics.*
Chapter 2 provides a basis for how these three mechanical constructs of swing are influenced by various musical factors. These factors can be divided into two categories: soloist-controlled factors and non-soloist controlled factors. The soloist-controlled factors include those that can be manipulated by the soloist in any given performance. These include: (a) metrical beat placement, (b) melodic character of the phrase, (c) intervals between eighth note pairs, (d) range, and (e) articulation. The non-soloist controlled factors are those that may influence the perceptual and technical aspects of the performer. These include: (a) underlying harmony of the improvisatory vehicle, (b) tempo of the improvisatory vehicle, (c) beat placement of the bass player, and (d) beat placement of the drummer. Each of these nine factors is observable, can be measured empirically, and will be assigned a metric. Metrical beat placement, melodic character of the phrase, intervals between eighth note pairs, range, articulation and tempo are categorical in nature. Beat placement of the bass player and drummer will be measured on a continuous scale.

Development of Two Hypothetical Latent Variable Models

Two confirmatory factor analysis (CFA) models will be used in this study. Standard CFA models have three characteristics: (a) Each indicator is a continuous variable represented as having two causes: a single underlying factor that the indicator is supposed to measure and error, (b) measurement errors are independent of each other and of the factors, and (c) all associations between the factors are unanalyzed (Kline, 2005, pp. 166-167). Since the proposed models consist of continuous and categorical indicators, non-normal distributions and bias may occur. In this case, three options are available if distributions are abnormal: (a) use of a
corrected normal theory method, (b) use of an estimation method that does not assume multivariate normality, or (c) the use of a normal theory method with nonparametric bootstrapping (Kline, 2005, pp. 195-197). Decisions upon the chosen method will be based on each model’s best fit. Multiple alternate but equivalent models will be utilized in this study for three reasons. First, both models reveal different sets of data that may be important to the pedagogical application of the data. Second, the lack of previous research in this area results in an absence of a priori factor categories. Without the statistical evidence of a priori categories, there is a possibility that the confirmatory factor analyses for the constructs of soloist controlled factors and non-soloist controlled factors may not provide enough statistical significance in their loadings to allow for the support of any latent variables. Third, if the musical factors are highly correlated to each other, they may have a hard time competing for shared variance. The interpretation of the latent variable will reveal itself in the factor analysis.

Both models fit the two necessary conditions in order to be identified: (a) the number of free parameters is less than or equal to the number of observations, and (b) every latent variable must have a scale (Kline, 2005, pp. 169-170). Model A contains 78 observations and 14 free parameters. Model B contains 78 observations and 56 free parameters. Each latent variable will be assigned a scale of 1.0.

Model A hypothesizes the existence of a three latent variable structure: (a) swing, (b) soloist controlled factors, and (c) non-soloist controlled factors. The latent variable of swing is a composite of observed variables that are hypothesized to directly influence the function of swing. These variables include eighth note duration,
beat placement, and note dynamics (see Figure 1.4). The latent variable of soloist-controlled factors is hypothesized to be a composite of musical factors that can be directly manipulated by the soloist, including metrical beat placement, melodic character, intervals, articulation, and range (see Figure 1.5). The latent variable of non-soloist controlled factors is hypothesized to be a composite of musical factors that cannot be directly manipulated by the soloist, including underlying harmony, tempo, bass beat placement, and drummer beat placement (see Figure 1.6).

*Figure 1.4. Hypothesized latent variable of swing.*

*Figure 1.5. Hypothesized latent model of soloist controlled factors.*
Soloist controlled factors and non-soloist controlled factors are hypothesized to have a direct effect on the overall consistency of swing. Pedagogically, this may provide important insight into how much of a role the soloist has in swing. Model A (see Figure 1.7) is one of the proposed hypothetical structures of this study.
Model A does not suffice in demonstrating how soloist-controlled factors and non-soloist controlled factors correlate to the construct variables of swing. Model B (see Figure 1.8) is another of the proposed hypothetical structures in this study.
Pedagogically, this may provide insight into what specific music musical factors should be addressed while teaching swing rhythm.

![Diagram](image_url)

**Figure 1.8.** Model B. Hypothesized one latent Swing Model (SM-B).

Support for these hypothesized models comes from published writings and discussions about jazz and research literature pertaining to the microstructural elements of jazz rhythm. This literature has indicated that beat placement, note
dynamics, and eighth note duration are the fundamental constructs that influence the function of swing. This model assumes that the musical factors of metrical placement of the beat, melodic character of the phrase, intervals, articulation, underlying harmony, tempo, time feel of the bass player, and time feel of the drummer influences the beat placement, note dynamics, and eighth note duration.

**Purpose of the Study and Related Research Questions**

The purpose of this study is to create and test two hypothesized models for swing in jazz performance. Specifically, this study will answer the following research questions.

1. Do eighth note duration, beat placement, and note dynamics define Swing?
2. How much do the first-order factors of soloist controlled variables and non-soloist controlled variables influence the second-order factors of eighth note duration, beat placement, and note dynamics?
3. How much do soloist controlled factors and non-soloist controlled influence swing?
4. Can a hypothesized model of swing be created and statistically tested?
5. If consistency of swing can be predicted, what are the best combinations of predictors?

**Delimitations of the Study**

The data of study are limited to the objective, acoustical analysis of events pertaining to swing rhythm in jazz performance. These variables can be physically measured in a jazz performance. Due to the subjective nature and inherent problems
pertaining to the perception of swing, measurement and evaluation of the perception of swing will not be considered. This study is limited to the empirical measurement of monophonic, tenor saxophone performances of one person to assure reliability.

**Definitions**

*Articulation.* The manner in which the onset of a note is started. The onset of a note can either be started with the tongue or started with an air attack (slurred).

*Asynchrony.* Asynchronies refer to the difference in onset or attack times of two or more instruments that perceptually appear to play simultaneously. Asynchronies are measured in milliseconds.

*Note dynamics.* The term used to identify the factor that represents the notion of “democratization of rhythmic values.” This measurement quantifies the acoustical loudness of each eighth note performed and is calculated utilizing MIRtoolbox’s *mirrms* (root square mean function).

*Beat placement.* The term used to identify the factor that represents the vertical measurement of a performers time-feel. This measurement quantifies the asynchronous timing between ensemble members relative to the underlying perceptual pulse of the music. More specifically, the empirical output of vertical measurement is quantified by marked deviations from the perceived pulse measured in milliseconds. Beat placement is one of the three constructs of swing rhythm.

*Beat-upbeat ratio (BUR) value.* BUR value is defined as the temporal proportion between two subsequent eighth notes starting on the downbeat and ending on the upbeat. It will be measured by calculating the proportion between two consecutive eighth notes by dividing the durational value of the eighth note occurring
on the downbeat (measured in milliseconds) divided by the durational value of the
eighth note occurring on the upbeat (measured in milliseconds). In this study, BUR
values serve quantify the linear time-feel measurement and are referred to as “eighth
note durations.”

**Democratization of rhythmic values.** The broad term that refers to the
accentuation or note dynamics of particular notes in a jazz performance (Schuller,
1968, p. 6). This notion will be referred to as “note dynamics” and is defined as
relative signal energy for each individual eighth note performed. This measurement is
limited to performed solo interpretations. Note dynamics was calculated utilizing
MIRtoolbox’s mirrms (root square mean function):

\[ x_{\text{rms}} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2}{n}} \]

**Duration.** The onset of a note subtracted from the offset of the same note,
measured in milliseconds (ms).

**Harmonic character.** The measure of the specific harmonic chords that
support the eighth notes being analyzed.

**Interonset timing intervals (IOI).** The amount of time elapsing between
successive notes measured in milliseconds (Pressing, 1987). The time interval
between the onset of the tone and the onset of the immediately following tone. It is
the sum of a tone’s physical duration and the pause duration between the offset of the
tone and the onset of the next (Friberg & Battel, 2002, p. 200).

**Interval.** The distance between two successive eighth notes (the eighth note
downbeat and the eighth note upbeat).
Isochronous sequence. A sequence of sound that occurs regularly, or at equal time intervals.

Jazz. A form of music that can be defined by three related meanings: 1) a musical tradition rooted in performing conventions that were introduced and developed early in the 20th century by African Americans; 2) a set of attitudes and assumptions brought to music-making, chief among them the notion of performance as a fluid creative process involving improvisation; and 3) a style characterized by syncopation, melodic, and harmonic elements derived from the blues, cyclical formal structures and a supple rhythmic approach to phrasing known as swing (Tucker, 2001).

Mean Onset Time (MOT). The average onset of times played simultaneously by n players, measured in milliseconds. It is defined by the formula:

\[
\bar{w} = \frac{w_1 + w_2 + \ldots + w_n}{n}
\]

(Rasch, 1979, p. 122).

Measure. A segment of time defined by a set number of beats. This study is limited to four quarter note beats per one measure.

Mechanical norm. The strict, metronomically correct representation of a rhythm.

Melodic character. The directional relationship between two consecutive eighth notes. The melodic character can either be ascending, descending, or constant.

Metrical beat placement. The specific reference point for each of the eight equally divided eighth note subdivisions within a 4/4 measure.

Nominal performance. A direct translation of the score into physical variables, where all the notes of the same note value have the same nominal IOI, derived from
the tempo. A nominal performance often serves as a reference point for research on musical timing (Friberg & Battel, 2002, pp. 200-201).

**Eighth note duration.** The term used to identify the factor that represents the linear measurement of a soloist’s time-feel. This measurement quantifies the durational relationships between two consecutive eighth notes (the crasis and anacrusis) contained within one full beat. Eighth note duration is one of the three constructs of swing rhythm.

**Offset.** The physical end of a tone (Friberg & Battel, 2002, p. 200).

**Onset.** The physical start of a tone (Friberg & Battel, 2002, p. 200).

**Onset difference time (ODT).** The relationships of relative onset times (ROTs) between instruments, measured in milliseconds. It is defined by the formula:

\[
d_{1,2} = v_2 - v_1, \quad d_{1,3} = v_3 - v_1 \ldots \quad d_{n-1,n} = v_n - v_{n-1} \quad (Rasch, 1979, p. 122).
\]

**Performance context.** The performance context is defined as either the inclusion or exclusion of accompaniment during a musical performance. Performance context will be coded as 1= solo, 2= with piano, bass, and drums accompaniment.

**Relative Decibel Measurements (RDM).** The difference between the Mean Decibel Measurement (MDR) and actual decibel measurement of each eighth note performed by the soloist in any given performance.

**Range.** The distance from the lowest to the highest pitch that can be played. The range will be categorized into four targeted areas on the saxophone defined by the transposed pitches as performed on the tenor saxophone. The four targeted areas will be coded as: low (Bb3→ F4), medium (G4→ C5), high (D5→ F#5), and altissimo (G5+).
Relative onset time (ROT). The difference between the mean onset time (MOT) and actual onset time of a performer, measured in milliseconds. It is defined by the formula: \(v_1 = w_1 - \bar{w}, \ v_2 = w_2 - \bar{w}, \ldots \ v_n = w_n - \bar{w}\) (Rasch, 1979, p. 122).

Rhythmic flexibility: A performer’s discrimination (interpretation) of time through the performance of sequential rhythmic figures against an underlying, isochronous pulse.


Swing. The latent variable that is hypothesized to be constructed of three factors: eighth note duration, beat placement, and note dynamics. Swing is the amount of shared variance among these three hypothesized factors.

Swing eighth notes. The subbeat of the tactus performed unevenly in a long short pattern.

Swing ratio. The relationship of the note duration between two successive eighth notes (starting on the downbeat and ending with the upbeat) with an implied swing style (triplet) subdivision. In this study, the swing ratio will be measured by the Beat-Upbeat Ratio (BUR) value and Upbeat-Beat Ratio (UBR).

Tempo. The tempo marking, or mean tempo of the full musical excerpt being analyzed (Friberg & Battel, 2002, p. 201).

Time feel. The manner in which a performer rhythmically interprets the eighth note in a jazz performance.

Tone duration. The time interval between the physical start of the tone and the end of the same tone, measured in milliseconds (Friberg & Battel, 2002, p. 200).
**Upbeat-beat ratio (BUR) value.** UBR value is defined as the temporal proportion between two subsequent eighth notes starting on the upbeat and ending on the downbeat. It will be measured by calculating the proportion between two consecutive eighth notes by dividing the durational value of eighth note occurring on the upbeat (measured in milliseconds) divided by the durational value of the eighth note occurring on the downbeat (measured in milliseconds). In this study, UBR values serve quantify the linear time-feel measurement and are referred to as “eighth note durations.”
CHAPTER TWO

Review and Related Literature

The purpose of this study is to create and test two jazz swing models. This chapter reviews the literature on expression and meaning in jazz performance. It also looks at the empirical literature of microrhythmic jazz performance analysis. The literature that uses variables employed in this study will be the focus. The order of this review will be: (a) philosophical foundations of musical meaning, expression and structure in jazz, (b) elements of jazz rhythm, and (c) empirical research on microstructure, rhythm, and expression in jazz performance.

Philosophical Foundations of Musical Meaning, Expression, and Structure in Jazz Performance

Leonard Meyer and Charles Keil. In 1966, Charles Keil developed a paradigm for understanding the rhythmic quality of swing (Keil, 1966, p. 339). His theory of “Engendered Feeling,” a direct contradiction to Leonard Meyer’s theory of “Embodied Meaning” from ten years earlier, sought to describe the innate emotion and meaning found in the production of jazz rhythm (Meyer, 1956). More specifically, it was an early attempt to describe the perception of time-feel inherent in a jazz performance that could not be captured through notation. He argued that a new processual methodology needed to be developed in order to analyze jazz rhythm and time-feel with significant results and connotations relevant to the field of jazz.
Keil’s opposition of Meyer’s theory laid in its application to musical systems outside of the Western compositional tradition. He claimed that deficiencies occur in applying Meyer’s theory to the processual, improvised, and spontaneous nature of jazz improvisation. Expression, he claimed, is not found in the syntax of the music alone:

This procedure assumes that for analytic purposes music can be fixed or frozen as an object in a score or recording, and it implies not only a one-on-one relationship between syntactic form and expression but a weighting in favor of the former factor to the detriment of the latter. (Keil, 1966, p. 337)

In addition to syntax, modes of presentation, understanding, and response have to be taken into consideration in order to comprehend the intricacies of a jazz performance. It is not only the syntactic, structural relationships that demonstrate embodied meaning, but also the rhythmic drive, groove, timing, and texture that interact equally and in a complex manner to yield a Gestalt.

Keil’s concept of engendered feeling merely refers to the swing feel or forward-moving rhythmic propulsion inherent in jazz rhythm. It stems from the asynchronous manipulation of timing and beat placement between ensemble members. This microstructural push and pull, or deviations from the fundamental metronomicity, conveys information about musical structure. Furthermore, it is what gives jazz its fundamental swing feel. This push and pull, or “participatory discrepancy” (PD), can be categorized in two ways: processural and textural:

For “participatory discrepancies” one could substitute “inflection,” “articulation,” “creative tensions,” relaxed dynamisms,” “semiconscious or unconscious slightly out of synchnesses.” For “process” one could substitute “beat,” “drive,” “groove,” “swing,” “push,” etc., and for “texture,” one could substitute “timbre,” “sound,” “tone qualities”… etc. (Keil, 1987, p. 275)
Figure 2.1 organizes and compares the major tenants of both Meyer and Keil’s philosophical approach to musical meaning and expression.

<table>
<thead>
<tr>
<th></th>
<th>Embodied Meaning</th>
<th>Engendered Feeling</th>
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<tbody>
<tr>
<td>1. Mode of construction</td>
<td>Composed</td>
<td>Improvised</td>
</tr>
<tr>
<td>2. Mode of presentation</td>
<td>Repeated</td>
<td>Single performance</td>
</tr>
<tr>
<td>3. Mode of understanding</td>
<td>Syntactic</td>
<td>Processual</td>
</tr>
<tr>
<td>4. Mode of response</td>
<td>Mental</td>
<td>Motor</td>
</tr>
<tr>
<td>5. Guiding principals</td>
<td>Architectonical</td>
<td>“Vital drive”</td>
</tr>
<tr>
<td></td>
<td>(retentive)</td>
<td>(cumulative)</td>
</tr>
<tr>
<td>6. Technical emphases</td>
<td>Harmony/melody</td>
<td>Groove/meter(s)</td>
</tr>
<tr>
<td></td>
<td>/embellishment</td>
<td>/rhythm (horizontal)</td>
</tr>
<tr>
<td>7. Basic unit</td>
<td>“Sound term” (phrase)</td>
<td>Gesture (phrasing)</td>
</tr>
<tr>
<td>8. Communication</td>
<td>Linguistic</td>
<td>Paralinguistic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(kinetic/proxemic)</td>
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<tr>
<td>9. Gratifications</td>
<td>Deferred</td>
<td>Immediate</td>
</tr>
<tr>
<td>10. Relevant criteria</td>
<td>Coherence</td>
<td>Spontaneity</td>
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</table>

*Figure 2.1. Embodied meaning versus engendered feeling (Keil & Feld, 1994).*

**Performer-Centered Views on the Elements of Jazz Rhythm**

The subtle nuance of processural and textural participatory discrepancy has a substantial implication of a performer’s personalized sense of time-feel in jazz performance. “Time-feel” is an important performance characteristic that expresses the unique interpretation of a performance in the jazz genre (Liebman, 2003, p. 21). The degree of rhythmic phrasing a performer expresses can be even more revealing than any type of melodic or harmonic expression.

This expression, or “groove,” is most obviously expressed to the listener in a string of eighth note patterns. When defining time feel, Liebman writes,
I am not discussing aspects of syncopation, rhythmical augmentation and diminution, hemiola, etc., which describe actual rhythmical constructs themselves. No matter what rhythms are employed, be they eighths, sixteenths or whatever, it is the way these rhythms are played which determine the ambiance or feel of the music. I would venture to say that the emotional aspect of the music is greatly affected by how rhythm is played, maybe more so than what the rhythms themselves are made up of. A plausible definition of a good jazz rhythmic feel should involve words like “accurate” (meaning as close as possible to the original and ongoing pulse), “even” (connotating a smooth rather than choppy or awkward flow), “variable” (meaning not entirely predictable using a variety of rhythms) and of course our original word “swinging.” (Liebman, 2003, p. 22)

Liebman describes five elements that constitute time feel and phrasing: (a) articulation, (b) dynamics, (c) “the space between,” (d) nuance, and (e) beat placement. Articulation refers to the manner in which a note is attacked. He suggests that when discussing articulation, consideration should be given to the specific jazz style being performed: “As a generalization we could say that the vast majority of articulations heard in jazz fall somewhere between staccato and legato with an incredibly vast palette of variety” (Liebman, p. 23). Liebman refers to dynamics in terms of articulation and accent placement within the melodic line. He suggests that the soft spectrum of dynamics in a jazz performance include a ghost note, swallowed note, or muffled tone. Similar to articulation, the degree in which accents are used is spontaneous and is subject to variability. “The space between” refers to the swing-ratio. This aspect of performance is directly related to the performers’ conceptualization and expressivity of swing and time feel. Nuance, according to Liebman, is the most individualized aspect of time feel, as it encompasses common devices that are specific to the instrument and control of the performer: vibrato, smears, portamento, grace notes, use of harmonics, bent tones, vocalizations, etc.
Lastly, Liebman refers to beat placement as the subtlest of all time feel characteristics:

This is where the musician places his pulse in relation to the ongoing accompaniment. Because there is a reference point (or several depending upon the number of accompanists) this is a very subjective area and totally affected by the improviser’s concept in the moment… If we conceive of a beat not as a point in time but an area or measurement of a distance, then we have an entire “space” to play with as far as available choices where one can place their down and subsequent upbeats. (Liebman, 2003, p. 23)

Problems with Defining and Measuring Swing Rhythm

The obstacles with perceptual and cognitive definitions of swing. With such rhythmic complexity inherent in music performance, Gabrielsson (1985) suggests that musical expression between the performer and listener “is meant to be realized by the sounding music, not by reading of a score” (p. 28). The engagement of an aural approach to the realization of rhythmic deviation introduces the listener to an experience in which perception and conceptualization is freed from the limitations of rhythmic categories. 

Berliner (1994) explains that the jazz community has formulated aural descriptors as a means for describing their perception of jazz rhythm:

Imagining the beat as an “elliptical figure,” the drummer or bass player can play either “ahead of the beat” (that is, on the front part of the elliptical figure), “behind the beat” (that is, on the very end of the elliptical figure or in varying degrees toward the center of the figure), or “on the beat” (that is, the center of the figure). (p. 151)
Pianist Fred Herch further develops this notion:

… there should be ten, fifteen different kinds of time. There’s a kind of time that has an edge on it for a while and then lays back for a while. Sometimes it rolls over the bar, and sometimes it sits more on the beats. That’s what makes it interesting. (Berliner, 1994, p. 151)

**Perception of music versus actual acoustical events.** The convoluted nature of the timing relationships within an ensemble performance can cause discrepancies between one’s perception music and the actual acoustical events. Contrary to Gabrielson’s (1985) stance on the benefits of realizing music’s communicative value through aural understanding, Collier and Collier (1994) believe that assigning aural descriptors of timing relations is problematic for two reasons: (a) the listener’s preconceptions may influence their perception, and (b) incorrect preconceptions become engrained within the standard narrative of jazz history. Collier and Collier (2002) substantiated their claims with evidence that the perception of Louis Armstrong’s rhythmic timing is not in agreement with the actual acoustical events in two of his recorded solos.

These discrepancies not only occur within the listener, but they also occur on within the actively participating musician. Research has established that performer intention does not always equal performer execution. Prögler (1995) demonstrated that a drummer who perceived himself to be playing “behind the beat” actually was
playing “ahead of the beat.” Due to the possibility of discrepancies occurring between listeners’ and performers’ timing perceptions, the empirical analysis of timing relations is essential in understanding the true nature of jazz improvisation.

**Limitations of musical notation.** In jazz performance, musical notation is problematic. The accepted convention is the categorization of successive swing eighth note into a default value of a quarter note-eighth note triplet (Gridley, 1988). Conventional methods of “swing notation” cannot account for the subtle variations in the subdivisions of the swing eighth note. Notation, in this case, is merely an approximation and does not accurately express the performance. The approximation and representation of jazz time-feel into triplet notation may stem from the psychological principle of parsimony as well as the theory of categorization (Bruner, Goodnow, & Austin, 1956). Human perception and cognition strives to interpret and simplify complex information through a coding system of hierarchical arrangement. It is Bruner’s (1960) contention that “to perceive is to categorize, to conceptualize is to categorize, to learn is to form categories, to make decisions is to categorize.” However, this may be seen as a limitation because the process of simplifying input causes a certain degree of imprecision (Kroll, Rieger, & Vogt, 2010, p. 201).

Benadon (2006) explains the problematic nature of this over-simplistic paradigm:

Adhering to any fixed ratio constitutes a misrepresentation of the rich variety of expressive microstructures found in jazz. Rather than replacing the triplet paradigm, our aim as jazz scholars should be to emphasize the absurdity of ascribing to any rigid formula whatsoever. (p. 91)

Three attempts have been made to formulate an alternate notation system in order to adequately account for microstructural deviations in jazz performance. Stewart (1982) created a grid notation system that “represents the time value of each
beat as the distance between two adjacent, vertical lines on the grid (p. 3). Haywood (1993) suggested an adaptation to standard notation by adding arrows beneath the notes in order to define anticipations and delays. Benadon (2007) suggests using a cyclical graphing method to visually represent and organize expressive timing data. Although these experimental notation conventions offer innovative approaches to representing rhythmic deviations, a more sophisticated explanation is needed to explain all three constructs of swing: eighth note duration, beat placement, and note dynamics.

**Personalization of swing rhythm.** Deviations from the mechanical norm serve as an expressive feature that define the stylistic profiles of jazz artists (Bauer, 1993; Benadon, 2003; Benadon, 2006; Cholakis & Parsons, 1995; Collier & Collier 2002; Ellis 1991; Huang & Huang, 1994). This expressive feature of rhythm feel is engrained in each performer’s unique treatment of the eighth note triplet and can serve as a basis for perceptual differentiation between individual jazz performers and jazz ensembles. American jazz critic Martin Williams (1970) comments on the use of rhythmic expression as a means of personalization: “… developing a personally-articulated triplet not only has been an identifying mark for the great players, it has been an expression of the high individuality on which this music depends and which it celebrates” (p. 208).

These subtle nuances of a performer’s treatment of the eighth note differ not just stylistically, but also in terms of specific distinctions between groups and individuals.

…each of the great players has found his own way of pronouncing the [swing] triplet, expressed or implied… Roy Eldridge’s triplet doesn’t
sound like Louis Armstrong’s; Miles Davis’ didn’t sound like Dizzy Gillespie’s; Lester Young’s triplet was unlike Coleman Hawkins’; and Stan Getz’s is unlike Lester Young’s. (Williams, 1970, p. 208)

Even though musicians perform with rhythmic approaches that can be perceptually unique and recognizable, the rhythmic manipulation in their performances is restricted to a point of perceptual “acceptance” or “correctness” within the particular performance context. Sterns (1970) notes, “When one jazzman confides to that another ‘has no beat’- and there is no harsher criticism - he is impugning his metronomic sense” (1970, p. 4). Disparities among this perceptual “correctness” can even cause a hindrance in the overall musical performance: “… discrepancies in the way players interpret rhythm… are especially serious when they affect the rhythm section’s fundamental interaction” (Berliner, 1994, p. 395). A wide range of rhythmic variety exists between what is perceptually considered to be “swinging” and what is perceptually considered to be “not swinging.”

The underpinnings of these perceptual judgments seem to be linked by three common factors: (a) note duration of consecutive eighth notes, (b) placement of the beat in relation to the perceived pulse, and (c) note dynamics. Because the wide range of rhythmic variety in jazz performance often exists at the microstructural level, neither notation nor categorization is specific enough to capture this it. In addition, human perception and hearing is more selective than what notation can capture (Hirch, 1959). However, perception alone is not reliable enough to comprehend the exact measures of rhythmic deviation (Collier & Collier, 2002). A need exists to further explore these factors and their relationship to how swing functions.
Empirically Testing the Constructs of Swing

The study of microstructure in music stems from the cognitive psychological research of the 1950s and 1960s. Expressive microstructure is an integral part of musical structure that accounts for the varied, subtle, and distinctive forms of tone and rhythm. The principal features of microstructure include the characteristic amplitude shapes for individual tones as well as duration deviations from specific note values.

Psychological interest in the microstructure of jazz performance began in the mid-1960s with specific consideration to the rhythmic relationships of eighth note pairs inherent in the swing style (Keil, 1966). Beginning in the late 1970s and 1980s, empirical investigation into the microstructural elements of a performer’s eighth note treatment began to demystify some of the properties and subtle nuances of jazz rhythm (Owens, 1977; Reinholdsson, 1987; Rose, 1989). These investigations initially sought to break down the swing component of jazz time feel through methods of linear and vertical measurement.

The linear measurement of time-feel (i.e., eighth note duration) quantifies the durational relationships between two consecutive eighth notes (the crusis and anacrusis) contained within one full beat. The empirical output of this linear measurement has been traditionally labeled as “swing-ratio” (Collier & Collier, 2002; Friberg & Sundström, 2002). There are two problems with using a “swing ratio” (i.e., 1.47:1.48) as a quantitative descriptor for eighth note durational relationships: (a) it is hard to compare relationships between eighth note pairs because a ratio does not provide a clear visual data point on a continuum, and (b) the ratio is redundant
because it would have to be calculated into its quotient for use in statistical analysis and processes. In order to compensate for these inadequacies, Benadon (2006) suggested the use the number derived from this quotient as a means to compare the relationships. The swing ratio’s quotient, defined as beat-upbeat ratio (BUR) value, will be used in this study to quantify the relationship between the eighth note durations of each eighth note pair that is analyzed. This value is perceptually associated with the expressive quality of the soloist’s melodic style (Benadon, 2006; Collier & Collier, 2002; Friberg & Sundström, 2002). In this study, this linear measurement will be referred to as “eighth note duration.”

The vertical measurement of time-feel (i.e., beat placement) quantifies the asynchronous timing between ensemble members relative to the underlying perceptual pulse of the music. The empirical output of vertical measurement is quantified by marked deviations from the perceived pulse measured in milliseconds. In particular, the beat placement relationships between performing members of the ensemble will be empirically defined by statistical methods. These methods include Mean Onset Time (MOS), Relative Onset Time (ROS), and Onset Difference Times (ODT). These values are linked to the perceptual “quality” of the ensemble groove created by the rhythmic tension and release between ensemble members (Keil, 1966). In this study, the vertical measurement will be referred to as “beat placement.”

Empirical testing of “democratization of rhythmic values” (i.e., note dynamics) has yet to be published in research literature. “Democratization of rhythmic values” is the broad generalization that refers to the amount of emphasis in which specific notes are performed. The acoustical loudness of each eighth note
performed will be measured and quantified in decibels (dB). The Mean Decibel Measurements (MDM) and Relative Decibel Measurements (RDM) will empirically define the relationships between eighth note decibel measurements. These values are linked to the perceptual “forward motion” or “vital drive” feeling in jazz performance (Hodier, 1956, pp. 207-209). In this study, this measurement will be referred to as “note dynamics.” Figure 2.3 characterizes the relationships of swing mechanical constructs.

**Empirical Research in Microstructure, Rhythm, and Expression in Jazz**

Owens (1977) conducted one of the earliest observational research studies in the microstructure of jazz performance. He used a melograph to transcribe a recording of Charlie Parker’s solo on “Parker’s Mood.” In using this method, Owens singled out the improvised solo from the accompaniment by using the loudness curve of the graphing procedure. The results from the graph allowed Owens the opportunity to empirically examine the details of Charlie Parker’s performance style in terms of his phrase shaping, vibrato, and overall melodic-improvisational approach. This technique was a small offshoot of a comprehensive study that deconstructed, documented, organized, and catalogued Parker’s motivic vocabulary. Although informative, this study lacks the systematic or experimental type of research of more recent studies.

Reinholdsson (1987) conducted a methodological pilot study on an eight-measure drum solo performed by Roy Haynes on the tune “Everytime We Say Goodbye.” The purpose of this study was to contribute strategies to scholarship by
Figure 2.3. Constructs of musical expression as displayed through jazz rhythm with supporting perceptual and empirical evidence.
displaying a particular methodology for analyzing aspects of rhythm in live jazz performances. Reinholdsson questions the validity and accuracy heavily based on his use of psychological and empirical observations as well as the relationship of the notational-based approach to transcription (aurally perceived) verses the direct and objective registrations of the physical sound.

The recording of the drum solo was put into an analog sound analysis program called MONA. The durations of the measurements have an accuracy of ± 10 ms and were plotted in terms of amplitude. Reinholdsson performed a total of nine registrations (R1-R9) by varying the bandwidth and center frequency. The framework for mechanical performance and mechanical deviations were recorded as ratio-mechanical norms and compared to the duration of the measurements notated by the aurally conceived transcription.

Reinholdsson’s results stressed the complications of the empirical analysis process. These included: (a) problems with perception of sound in the transcription process (particularly the discrepancies with aural perception and the recorded readings from MONA), and (b) discrepancies in performance analysis (the physical manifestations of rhythm-as-intended verses rhythm-as-perceived).

Reinholdsson calls for the future research into rhythm to include the full jazz ensemble with multi-channel recording. Specifically, researchers should investigate “the feasible changes and adaptations in the timing of the musicians as a result of interactive processes within the ensemble context (p. 121). He also advises to employ methodological pluralism, in which an analysis should begin in broad terms and progressively shift to an analysis in a more defined, microstructural scope.
Rose (1989) measured the eighth note timing relationships of all notes played by the drums, piano and bass in a play-along recording in three different mediums: swing-style, ballad, and Latin-style. In measuring asynchronization, Rose used deviations from the mean differences in onset times between piano, bass, and drums. Results showed that in the swing-style example, the order of beat placement from first to last include the drums, followed by the piano, and lastly the bass. The irony in this data is the placement order of the bass. In swing styles, the bass is perceptually considered to play “on top of the beat” in anticipation of the beat (Lawn, 1981) and it is considered to be the prominent timekeeper (Gridley, 1988).

In order to analyze the long-short eighth note beat divisions (swing ratio), Rose used two performance conditions: 1) three recorded performances of the piano, bass, and drums collectively, and 2) fifteen unaccompanied, solo performances from recorded jazz literature. His measurement tool was an ISQ Spectrum Analyzer. Rose found that in the unaccompanied, solo performances, the mean swing ratio was 2.38:1. In the collective performances, Rose’s reported mean swing ratio was 1.43:1. The mean swing ratio of all three instruments was 2.4 and all performed with approximately the same swing ratio.

Ellis (1991) designed an experimental research study that measured the swing ratio of three professional saxophonists. The study sought to describe the asynchronizations and long-short eighth note beat divisions (swing-ratio) that occur while playing with a prerecorded rhythm section tracks. The saxophonists were asked to perform various notated patterns based upon the blues form, using a Casio DH-100
MIDI wind controller. Each saxophonist performed three trials at 90, 120, 150, 180, and 210 bpm, totaling 15 trials total.

Ellis found that all three players delayed the onset relative to the bass in all cases. A two-way repeated measures ANOVA indicated significant differences among the means of the delays of attack with subjects \((p < .007)\), tempo \((p < .0001)\), and interaction between subjects and tempo \((p < .0001)\). Test statistics, degrees of freedom, and power were not reported.

In addition, a two-way repeated measures ANOVA indicated significant differences among the means of the swing ratio with subjects \((p < .007)\), tempo \((p < .001)\), and interaction between subjects and tempo \((p < .0001)\). Test statistics, degrees of freedom, and power were once again not reported.

Overall, it was found that the asynchronization between saxophonist and bass was in large part due to the performer delaying the onset attack (playing “behind the beat”). The swing ratio ranged between 1.474:1 and 1.871:1, averaging 1.701:1.

Collier and Collier (1994) took the full ensemble into account by observing the expressivity of jazz performances through the variance of tempo. This study examined and challenged the preconceived notions pertaining to the rhythmic relationships and beat placement of rhythm section instruments. Investigation into the understanding of the global nature of tempo provided insight into the more defined and subtle aspects of rhythmic performance.

Five data sets were collected to provide insight into the question: do jazz musicians prefer particular tempos? The data sets were organized by five categories: (a) band, (b) solo pianists, (c) alternative takes, (d) Teddy Wilson, and (e) Tempo
doubling. Audio segments were recorded using a stopwatch with the resolution of 1/100 of a second. Replicating the recording process two to four times checked reliability. The root squared mean between replications was 48.75 ms. 186 tunes or alternate takes were recorded and spanned a range of dates from 1917-1985. The recordings were classified into four stylistic periods in accordance with the standard narrative of jazz history: New Orleans, swing, bebop, and avant-garde. All recordings were in 4/4 time. Using Spearman’s rank order correlation, the durations of the recording segments were converted to standard metronome markings.

The results showed that jazz rhythm is particularly stable and appears to be an important factor in defining swing. Overall, the tempo variability was a product of precise control. 65 percent of the tunes never varied more than 5 percent. Overall, Collier and Collier conclude, “Rhythm is organized hierarchically… (and) timing preferences are tied to beat level, which is consistent with models of rhythm that give this level a fundamental priority (Collier & Collier, p. 241).

Cholakis and Parson’s (1995) observational study evaluated the ride cymbal patterns of 15 drummers. Until this research study, the common assumption was that drummers play in a strict triplet eighth note pattern at medium swing tempos. As the tempo increases, the triplet feel will approach a straight eighth note pattern and the distance between the two eighth notes becomes closer. As the tempo decreases, the distance between the two eighth notes increases.

Fifteen drummers’ cymbal patterns were analyzed from recorded performances ranging in tempi from 200-251 beats per minute. A total of two 4/4 measures were recorded and divided into equal eighth note subdivisions.
Measurements of the test included the number of swing points (the number of off beats followed by on beats), tempo, velocity (reported in decibels), duration (the size of the beat), and swing points range of variability. The idealized perfect quantized time (a triplet quarter note followed by a triplet eighth note in the time span of one beat) was notated numerically as 1000 for the downbeat and 1000+667 as the upbeat. Time measured from 1000 to 8667 on the graph. The range of variability was measured by calculating the difference between the idealized time and the executed time. Measurements of test reliability were not reported.

The overall results demonstrated two points: (a) the overall tendency of the drummers was to play closer to straight eighth notes as the tempo increased, and (b) only three of fifteen drummers played behind the beat. By looking specifically at Art Blakey’s results, Parsons and Cholakis drew three generalizations: (a) backbeats occur significantly earlier than downbeats, (b) backbeats (beats 2 and 4) were generally louder than downbeats (beats 1 and 3), and (c) backbeat durations were longer than downbeat durations.

Prögler’s (1995) quasi-experimental research analyzed the participatory discrepancies in the jazz rhythm section. His look into the three rhythm section instruments (piano, bass, and drums) as a whole in a jazz performance provided additional insight into the rhythmical relationships that define swing. His systematic methodology for measuring the degrees of discrepancy provides tangible ways of describing and quantifying swing conceptualization.

His study is both qualitative and quantitative in nature. Data for his study was gathered from three sources: (a) a recording session of a bass and ride cymbal
(specifically for the experiment), (b) recording sessions and interviews with two drummers and one bassists, and (c) a “music-minus-one” recording.

The foundation for his study was two recordings by bass players playing a twelve-bar blues in B flat along with a metronome at various tempi (60, 120, and 240 beats per minute). One was asked to play as close to the beat as possible. The second was asked to play “around” the beat. These two recordings then became the basis for overdubbed recordings of drummers playing the ride cymbal. The bassists were then asked to re-record ride taps to the bass lines for comparative purposes.

Prögler’s generalizations of the overall results of the study include the following: (a) participatory discrepancies occur in jazz performances and can be accounted for syntactically, (b) these discrepancies can be quantified precisely, (c) the amount of discrepancy is contextual, and (d) recognition and quantification of these discrepancies can lead to a tangible way of realizing and describing rhythm in jazz performances.

Collier and Collier (1996) conducted an experimental research investigation in order to provide analysis of the relationships between tempo and three drummers’ swing ratio. Using a MIDI drum pad, the three drummers were asked to perform a swing triplet feel and a straight triple feel at various tempi ranging from a beat duration of 2400 ms (extremely slow) to 214 ms (extremely fast). The results displayed divergent data from the three drummers. One drummer’s data demonstrated a negative correlation between tempo and swing ratio while performing a swing pattern. As the tempo increased, the ratio between eighth notes became smaller. The other two drummers demonstrated higher swing ratio data in mid-tempo
ranges. The results of this experiment were inconclusive as to the specificity of tempo direction in swing ratio data results. However, the study did demonstrate a tempo-dependent swing ratio. Lack of variability reporting and small sample size may have hindered the results of this study.

Abel (1996) conducted experimental research to answer the question, “How does swing work?” It was Abel’s strategy to demystify the vagueness associated with the description of the term, “swing.” The purpose of this study was to quantify the degree in which metrical displacement, swing ratio, beat placement, and attack velocity interact to create an agreeable listening experience based upon expectation from prior qualitative studies. Abel’s hypothesis is that: (a) well-formed performance will be preferred over the straight and perverse performance, and (b) metrical displacement will be preferred, with specific preference to direction and amount.

Abel chose and tested 20 Cambridge University students with an average of 12.95 years of listening and playing experience. The only criterion for selection was having performing for listening experience. To prepare the recorded selections, Abel used Unicorn’s ‘Performer’ (5.02) sequencing program on a Power Macintosh 7500-100 computer, a Yamaha SY99 digital synthesizer with an E-MU Proteus FX sound module. A 16-measure sample of a Bill Evans piano solo was used as the listening stimuli. A total of 15 permutations of the melody was played and the listeners responded to their preference to level of “swing” on a seven item Likert scale, ranging from 1= absolutely no swing to 7= swinging very much. Reliability of the performances included performance mode ($p < .0001$), metrical displacement ($p <$
The results showed that there was no significance between the straight and perverse performances. However, there was a significant difference for straight versus well formed (p<.0009) and for well formed versus perverse (p<.0001). The statistical significance of the least square means table shows that the only significance lies in the ahead-2 attack shift, showing that the listener threshold for agreeability is somewhere in the 10ms to 30ms delay range. Overall, at a tempo of 120 beats per minute, it seemed that swing rating is more dependent on the amount and direction of metrical displacement.

The weakness in the research of quantifiable measures of jazz performance prompted Busse’s (2002) evaluative and experimental research. He set out to objectively measure and analyze performance deviations (microstructures) from mechanical regularity and measure how experts rate the musical examples as being representative of the “swing style.”

Busse developed four performance models based on 281 one-measure performance samples using the Performer 5.02 sequencing program by Mark of the Unicorn, Inc. The 281 samples were produced by 33 solo performances by three jazz pianists. The performances were imputed via MIDI input. The specific microstructure variables measured were note placement, eighth note duration, and note velocity at discrete beat subdivisions. Averaging the data values of the performances and mathematical ratios representative of traditional jazz notation developed the performance models.
Forty-two jazz performers and educators were asked to evaluate the swing representativeness in the performance models once they were developed. In addition to the four derived performance models, they were asked to evaluate three additional models contrived from mathematical ratios.

The statistical results showed differences in each of the measured variables of the performers: downbeat note placement ($p < .001$), downbeat duration means ($p = .02$), upbeat note placement means ($p < .001$), and upbeat velocity means ($p = .02$). There was no reported statistical significance for the performers’ upbeat duration means ($p = .48$). No significant relationships were shown between performance tempo and beat placement, but there was a positive correlation between downbeat placement and upbeat placement ($r = .65$). Other positive correlations occurred between tempo and downbeat duration ($r = .3$), tempo and upbeat duration ($r = .57$), and downbeat duration and upbeat duration ($r = .52$). The judges found that the jazz swing style was represented more by the derived performance models than the mechanical performance models.

Overall, the following seven conclusions were drawn: (a) each performer demonstrated a personal approach to time feel, (b) downbeat note placement were generally performed behind the beat at all tempi, (c) upbeat note placements were generally performed later than the traditional triplet swing feel (swing $> 66.7\%$), (d) there was no relationship between upbeat note placement and tempo, (e) notes on the downbeats tended to be performed with longer duration than notes on the upbeat, (f), as tempo increases, performers elongate eighth note durations, and (g) there was only a slight tendency of upbeats to be accented.
Friberg and Sundström (2002) examined two aspects of swing ratio in two studies. First, they studied the variation of four drummers’ swing ratios on their ride cymbals. Second, they measured and compared the relationships of the swing ratios of a drummer’s cymbal accompaniment to a soloist’s swing ratio in a given performance. The study is descriptive, in that it gathers swing ratio data of the drummers, and it is correlational, since it compares the relationship of swing ratio to tempo.

Friberg and Sundström claim that there is a lack of documented evidence of the relationship between consecutive eighth notes with particular regard to tempo variance. The implications of this lack of evidence hinder pedagogical advancement in music expressivity and stylistic consideration. The purpose of this study has two intentions: (a) to measure the variation of ratios measured on the ride cymbal of drummers with varying styles, and (b) to measure the variation of ratios between the soloist and cymbal accompaniment. The underlying variable in both studies was tempo. The only delimitation of the study was that the measurements were based on consecutive eighth note patterns.

Operational definitions were offered for swing eighth note pattern and swing ratio. Swing eighth note pattern was defined as the lengthening of the odd eighth notes (eighth notes on the beat) and the shortening of the even eighth notes (eighth notes between the beat) to produce consecutive long-short patterns. The swing ratio is the relationship between these two notes. The relationships between two eighth notes that have the standard “triplet-feel” have the relationship of 2:1.
The first part of the study measured the variation of ratios on the ride cymbal of four drummers from six recordings. All musical examples were commercially available and all examples were swing style where the ride cymbal was used. A 10-26 second clip from the beginning of a melodic solo was used. The ratio was measured using a spectrograph. A tempo was established by ascertaining a downbeat and measuring 10-16 downbeats following the initial downbeat.

The results of the first method show a linear decrease in swing ratio with increasing tempo. The largest ratio is approximately 3.5:1 (beyond the length of a dotted eighth and sixteenth-note pattern) and the slowest ratio is approximately 1:1 (even eighth notes). The four drummers had similar swing ratios regardless of diverse drumming styles. There was also little variation of ratios contained in the same song sample.

The second method measured the swing ratios of all instruments in various audio segments. All musical examples were commercially available and all examples were swing style where the ride cymbal was used. The audio clip was selected on the basis of the soloist playing consecutive eighth note strings.

The results of the second method showed that at a medium tempo, soloists’ swing ratios were considerably lower than drummers’ swing ratios. All soloists’ means were below 2, which is closer to straight eighth notes. The drummers’ values were upwards of 4 for slow tempi. The soloists’ smaller swing ratios can be accounted for by the delay in the downbeat and their synchronized upbeats with the drummers.
The primary findings of both methods lead to discussions of approaches to pedagogical applications. Friberg and Sundström find three applications for the findings: (a) Understanding the relationship between tempo and swing ratio helps the teacher give constructive criticism and advice to a student in regards to swing style (particularly a beginning student), (b) feedback on parameters can improve advice on musical expressivity, and (c) awareness of swing ratio patterns allows the teacher and performer to prescribe a diagnosis for time and swing feel to avoid common pitfalls typically associated with inexperienced players. The study dispels and clarifies the discrepancy between common belief and the physical reality of time and swing feel. Suggestions for further research include revealing characteristics of musicians’ personal time and feel using the same research methods and analyzing musicians’ preferred timing characteristics in their approach to improvisation.

Collier and Collier (2002) quantified parts of two Louis Armstrong solos in order to analyze two key elements of swing: placement of the downbeats and the placement of the swing or triplet ratio (the swing ratio). The selection for the two tunes (Potato Head Blues and Cornet Chop Suey) was based on the inclusion of Armstrong solos over stop-time passages. Isolating the solo sections over stop time passages allowed Collier and Collier the ease of capturing Armstrong’s solo with clarity.

The solo segments were captured and transferred to waveform using Cool Edit 96. The coding was agreeable to approximately two or three cycles of a waveform (2ms or less). With this level of reliability, the variance was deemed as less likely to have an effect on the measurement outcomes.
Timing was reset to the beginning of each measure. Reference points for the stop-time sections were cued by the ensemble hits on beat one. Reference points for the non-stop-time sections were cued by Armstrong’s emphasis of the downbeats. If downbeats did not exist, markers were interpolated using analogous eighth notes. Dependent variables included discrepancy scores and proportional discrepancy. Reliability was reported as $p = .19$ for downbeat discrimination and $p = .58$ for upbeat discrimination.

Results show that Armstrong’s mean was 2 ms ahead of the beat. Autocorrelational analysis of *Cornet Chop Suey* showed positive correlations among the eighth notes in each particular measure. This means that the deviations from the mean occurred in groups.

In terms of swing ratio, 72 percent of the eighth note groupings in *Cornet Chop Suey* displayed longer durations of the first note. In *Potato Head Blues*, 95 percent of the groupings contained uneven eighth note durations in the same manner. Collier and Collier note that the relationships of these groups appear to be closer to 2:1 than originally hypothesized (typical swing eighth notes appear to range between 1.4:1 and 1.7:1). The mean of the ratios of the two songs were almost identical: 1.61:1 (30-40 ms later than even eighth notes would indicate). Collier and Collier’s conclusion was that the details of jazz rhythm should always be reviewed critically if it is discussed in terms of the unaided ear.

Ashley (2002) examined the nature of the expressive timing in ballad performance through two studies. The first study included the analysis of three interpretations of the Richard Rodgers and Lorenz Hart song, *My Funny Valentine,* by
three performers: Chet Baker Art Farmer, and Miles Davis. The three recordings were chosen for three reasons: (a) the proximity of their recording dates, (b) the performance skill of the artists, and (c) the diverse musical characteristics of the instrumental accompaniment.

Ashley measured the note onset attack points using SoundEdit 16 software on a Macintosh computer. The onsets of the tones were defined as the amplitude zero crossing most immediately preceding the beginning of the (quasi) periodic portion of the tone. Using this definition in addition to taking the mean of three separate measurement periods, the error measurement is considered to be \( \pm 3-5 \) milliseconds. The onset times of the solo performances were compared to the onset times of bass. Furthermore, the attack-time displacement (AD), was measured against the nominal performance of the original print notation of the melody to *My Funny Valentine*.

The results of the first study indicated that tempo was non metronomic, yet extremely well controlled. The tempo was calculated for the first 16 measures of each performance by measuring the interonset interval of the bass from one downbeat to the following downbeat. The range of standard deviation from the mean tempo was 0.8-3.0 beats per minute (bpm). This small range supports the use of tempo as a controlled underlying pulse against the melody for measurement purposes.

Ashley found that the deviations in tempo were extreme, ranging from -.38-1.4%. In addition, a noticeable motivic contour was exhibited. This is related to a “delay-accelerate” strategy in which the soloists would delay the beginning of the phrase and accelerate the end of the phrase in order to compensate for time lost.
Lastly, there seemed to be a sense of “cadential anchoring,” in which the soloist would align with the accompaniment at important cadential positions.

Ashley’s second study was the analysis of expressive timing in two takes of the song *Naima*, as recorded by John Coltrane. The same method of measurement was used in this study. Ashley found that the range of standard deviation from the mean tempo was 0.4-0.7 (0.7-1.7% of tempo). This small range again supports the use of tempo as a controlled underlying pulse against the melody for measurement purposes. By comparing the two takes, Ashley found a relatively “straight playing style,” in which the flexibility of the beat placement was rigid and in time. The alternate take revealed that Coltrane’s beat placement was on average, late in nature. Also, there was less overt rhythmic expression performed in the melody of *Naima* compared to *My Funny Valentine*. This indicates that the performer is less likely to take rhythmic liberties on a song that is less familiar to the audience.

Benadon (2006) conducted an observational study of the temporal relationships between subsequent eighth notes performed with a swing feel in the context of instrumental improvised jazz solos (Beat-Upbeat Ratio, or BUR). The BUR was calculated as the proportion between the durational values of the first eighth note to the durational value of the second eighth note. Previous microrhythm studies neglect the relationship of the swing eighth note to time and pitch collectively. Although aspects of time are prevalent in some studies (Busse, 2002; Collier and Collier, 1994; Friberg and Sundström, 2002; Prögler, 1995), discussion of pitch is excluded. Benadon examined the nature of the jazz eighth note with the intent to
explain their relationships to melody, harmony, phrase structure, musical personality (personalization), and the “swing-triplet” concept.

Benadon examined and recorded the BUR measurements of a total of thirty-eight recorded solo improvisations using the digital sound editor Sound Forge 4.0 on a home personal computer. There were four criteria for the recorded examples: (a) the example must be taken from a string of at least 8 eighth notes, (b) the eighth note pattern could not be from a double-time passage or non-swing style performance, (c) the tempo was under 250 beats per minute, (d) the example was taken from a 4/4 metered performance, and (e) the quality of the recording had to be clear enough for an unambiguous discrimination reading.

Benadon’s results suggest that expressive microrhythm aid in the articulation of phrase structure in three ways: (a) shifts in harmony and melodic character sometimes correlate to changes in BUR values, (b) higher BUR values occur at cadential phrase endings, and (c) motivic repetition and sequencing correlate to repetitive BUR measurements. Personalizations of BUR measurements were represented by histograms. Although no specific test reliability was documented, one can draw parallels between players’ distinct rhythmic styles and BUR measurements by outlining the central tendencies and distribution curve of the data provided.

Results show that there is not an adherence to the triplet feel paradigm as discussed in the cannon of jazz history and pedagogy. The divergence from this general rhythmic model demonstrates the abundant array of expressivity found in the rhythmic feel of jazz performance.
Honing and de Haas (2008) examined the relationship of swing ratio and tempo by analyzing three drummer performances on a full MIDI drum set. There were three improvements with this research design as opposed to previous designs: (a) swing ratios were systematically probed in the tempo ranges of 100-240 bpm in order to complement previous studies, particularly at slower tempi, and (b) performances were repeated in order to check for variability, and (c) the use of a full MIDI drum kit, as opposed to one drum pad, mimics real-life performance situations.

The research questions for this study include: (a) how much control do drummers actually have over their swing ratio? (b) Does swing ratio scale linearly with tempo? (c) Is there a threshold in eighth note duration around 100 ms?

Three professional musicians were asked to play a swing excerpt at nine different beat durations: 250, 300, 340, 380, 420, 460, 500, 540, and 580 ms with sixteen repetitions. The tempi were marked using a metronome.

The drummers performed with a high consistency and low variability between their individual performance styles ($r = .49$, $p < .0001$; $r = .60$, $p < .0001$; $r = .66$, $p < .0001$). This demonstrates that the drummers performed with control. This was measured by comparing their standard deviations from the mean swing ratio in SPSS. Considerable differences were found in the performance style of the three drummers by running ANOVA with the drummer and tempo as factors:

$$F(8, 3419) = 1113.82, p < .0001, \eta_p^2 = .72,$$
$$F(2, 3419) = 376.94, p < .0001, \eta_p^2 = .18,$$
$$F(16, 3419) = 177.65, p < .0001, \eta_p^2 = .45.$$

Results also showed that swing timing did not scale proportionally with tempo as was suggested in Friberg and Sundström (2002): $r = .20$, $p < .0001$. Lastly, it was
found that in an eighth note pairing, the second eighth note duration was linear in beat duration without support for a lower limit around 100 ms as found in Friberg and Sundström (2002): $r = .94, p < .0001$.

**Summary of jazz related research.** The results of the musicological research and literature pertaining to microrhythm can lead to the following conclusions: (a) jazz rhythm can be analyzed and evaluated empirically with reliable results, (b) jazz rhythm is stable and is an important factor in defining swing, (c) the relationship between the space between swing eighth notes (swing ratio) and tempo are indirectly proportionate (As tempo increases, the triplet feel approaches a straight eighth note pattern and the distance between the two eighth notes becomes closer. Conversely, as tempo decreases the eighth notes take on more of a triplet feel and the distance between the two eighth notes increases), (d) as a generalization, drummers tend to play on the beat or ahead of the beat as opposed to behind the beat, (e) the relationship microrhythmic variation as a variable of interplay and ensemble members is contextual, (f) changes in harmony yield changes in swing ratio, and (g) each musician has a personal approach to time feel.

The experimental research (Abel, 1996; Busse, 2002) particularly demonstrates several implications pertinent to the assessment and evaluation of jazz: (a) changes in microrhythm are audible to the natural ear, (b) as tempo increases, musicians elongate eighth note durations, (c) notes on the downbeat tend to be longer than notes on the upbeat, and (d) there is only a slight tendency to accent upbeats. Figure 2.4 outlines content analysis of results from the research literature reviewed.
<table>
<thead>
<tr>
<th>Variable (s)</th>
<th>Study</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tempo</td>
<td>Collier &amp; Collier (1994)</td>
<td>• Tempo varies according to the particular points in the piece and particular points in the performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Tempo variations are generally systematic, unconscious, and deliberate</td>
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<td></td>
<td></td>
<td>• Tempo variations do not vary more than 5 percent</td>
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<td></td>
<td></td>
<td>• Tendency of tempos can be categorized into three groups: (a) slow, 117MM, (b) medium, 160MM, and (c) fast, 220-230MM</td>
</tr>
<tr>
<td>Eighth note duration</td>
<td>Rose (1989):</td>
<td>• Beats 2 and 4 are generally lengthened and beats 1 and 3 are generally shortened.</td>
</tr>
<tr>
<td>Eighth note duration</td>
<td>Cholakis &amp; Parsons (1995):</td>
<td>• Drummer’s undivided beats were played consistently shorter than the divided ones.</td>
</tr>
<tr>
<td>Eighth note duration and underlying</td>
<td>Benadon (2006)</td>
<td>• Shifts in harmony and melodic character sometimes correlate to changes in BUR (Beat-Upbeat ratio) values,</td>
</tr>
<tr>
<td>harmony</td>
<td></td>
<td>• Higher BUR values occur at cadential phrase endings</td>
</tr>
<tr>
<td>Eighth note duration and metrical</td>
<td>Benadon (2006)</td>
<td>• BUR ratios are not uniform within a phrase. They oscillate considerably from beat to beat</td>
</tr>
<tr>
<td>placement of the beat</td>
<td></td>
<td>• BUR values increase through the bar where as quarter eighth note durations decreases</td>
</tr>
<tr>
<td>Eighth note duration</td>
<td>Benadon (2006)</td>
<td>• Notes on the downbeats tended to be performed with longer duration than notes on the upbeat</td>
</tr>
<tr>
<td>Eighth note duration and tempo</td>
<td>Busse (2002)</td>
<td>• As tempo increases, performers elongate eighth note durations</td>
</tr>
<tr>
<td>Eighth note duration</td>
<td>Collier &amp; Collier (2002):</td>
<td>• The total mean of analyzed swing ratios of were almost 1.61:1 (30–40 ms later than even eighth notes would indicate)</td>
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<tr>
<td></td>
<td></td>
<td>• 83.5 percent of eighth note pairs displayed longer durations of the first note</td>
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<td></td>
<td></td>
<td>• Swing ratio ranges between ranges between 1.4 to 1 and 1.7 to 1</td>
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<tr>
<td>Eighth note duration</td>
<td>Rose (1989)</td>
<td>• Average swing ratio in a ballad 2.38:1</td>
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<tr>
<td>Eighth note duration</td>
<td>Reinholdsson (1987)</td>
<td>• Average swing ratio ranged from 1.48:1 to 1.82:1</td>
</tr>
<tr>
<td>Eighth note duration and tempo</td>
<td>Ellis (1991)</td>
<td>• Average swing ratio was 1.7:1</td>
</tr>
<tr>
<td>Eighth note duration and tempo</td>
<td>Ellis (1991) Cholakis &amp; Parsons (1995) Friberg &amp; Sundström (2002)</td>
<td>• Swing ratio and tempo are indirectly proportional. As tempo increases, the swing ratio decreases and becomes closer to straight eighth notes</td>
</tr>
<tr>
<td>Eighth note duration and tempo</td>
<td>Collier and Collier (1996)</td>
<td>• Swing ratio is tempo-dependent</td>
</tr>
<tr>
<td>Eighth note duration</td>
<td>Friberg &amp; Sundström (2002)</td>
<td>• Instrumental soloists generally have smaller (less triplet oriented) swing ratios than the rhythm section</td>
</tr>
<tr>
<td>Beat placement</td>
<td>Rose (1989)</td>
<td>• Asynchronization of nominally simultaneous tones by different instruments occurred. Tendency was for the drums to hit first, the piano to hit second, bass to hit last</td>
</tr>
<tr>
<td>Beat placement</td>
<td>Reinholdsson (1987)</td>
<td>• Deviations in the mechanical norm of the drums equals 5-30ms</td>
</tr>
<tr>
<td>Beat placement and tempo</td>
<td>Ellis (1991)</td>
<td>• Beat placement is not proportional to tempo. As tempo increases, beat placement tends to become more behind the beat</td>
</tr>
<tr>
<td>Beat placement</td>
<td>Prögler (1995)</td>
<td>• Discrepancies in ensemble beat placement is contextual</td>
</tr>
<tr>
<td>Beat placement and tempo</td>
<td>Busse (2002)</td>
<td>• Downbeat note placement were generally performed behind the beat at all tempi • Upbeat note placements were generally performed later than the traditional triplet swing feel, (swing &gt; 66.7%) • There was no relationship between upbeat note placement and tempo</td>
</tr>
<tr>
<td>Note dynamics</td>
<td>Busse (2002)</td>
<td>• There was only a slight tendency of upbeats to be accented</td>
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</table>

*Figure 2.4. Content analysis of the review of related literature.*
CHAPTER THREE

Method

The purpose of this study was to create and test two jazz swing models. The literature review in Chapter 2 and logic suggest that it was appropriate to create and test two hypothesized latent variable models to distinguish how the three observable factors of eighth note duration, beat placement, and note dynamics function together to form the unobserved, latent variable called swing. The following chapter outlines the necessary procedures for testing the two hypothesized models. The specific order of this investigation proceeded as follows: (a) gathering of musical variables and measures, (b) data collection procedures, (c) development of two hypothetical latent variable models, (d) calculation of a power analysis and determination of minimal sample size, and (e) data analysis procedures.

Gathering of Musical Variables and Measures

Musical variables. Research literature in jazz and non-jazz related areas has yielded numerous factors that influence eighth note duration, beat placement, and note dynamics. Upon examination of this research literature, an exhaustive list of factors stemming from many disciplines were discovered: Information processing research literature (motor control, plasticity, tactile feedback, kinetics, psychoacoustics, sensorimotor maturation), psychological research literature (personality, mood, motivation), performance achievement research literature
(technical ability, skill level), musical cognition research literature (perception of grouping structure, perception of rhythm and meter, key inference, musical expectation, emotional and affective arousal response), physiological research literature (age, heart-rate, blood-pressure), and music psychology research literature (tempo, meter, phrase structure, melodic character of the phrase, motivic repetition and sequencing, phrase shifting, intervals between notes, volume, articulation).

The collected variables were separated into two categories: musical factors and non-musical factors. The non-musical factors were then disregarded. The remaining variables were examined for redundancy, appropriateness, and testing feasibility. These variables were then categorized into soloist-controlled factors and non-soloist controlled factors. Figure 3.1 summarizes where the resulting variables utilized in this research study were previously analyzed.

<table>
<thead>
<tr>
<th>Constructs of swing</th>
<th>Soloist-controlled musical factors</th>
<th>Non-soloist controlled musical factors</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Eighth note duration</td>
<td>Beat placement</td>
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<tr>
<td>Abel (1996)</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Ashley (2002)</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Benadon (2006)</td>
<td>x</td>
<td>x</td>
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<td>Busse (2002)</td>
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<tr>
<td>Cholakis &amp; Parsons (1995)</td>
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<td>Collier &amp; Collier (1994)</td>
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<td>Collier &amp; Collier (1996)</td>
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<tr>
<td>Collier &amp; Collier (2002)</td>
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<td>x</td>
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<tr>
<td>Collier &amp; Wright (1995)</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
Constructs of swing | Soloist-controlled musical factors | Non-soloist controlled musical factors
--- | --- | ---
Eighth note duration | Beat placement | Note dynamics | Metrical beat placement | Melodic character | Motivic repetition | Intervals | Articulation | Range | Underlying harmony | Tempo | Bass beat placement | Drums beat placement

Ellis (1991) | x | x | x
Honing & Haas (2008) | x | x | x
Owens (1977) | x | x | x
Pressing (1987) | x | x | x
Prögler (1995) | x | x | x
Reinholdsson (1987) | x | x | x
Rose (1989) | x | x | x

*Figure 3.1.* Variables utilized in previous research studies.

**Measures and operational definitions.** The following measures were gleaned through the resulting data from the digital analysis of the recorded musical examples:

**Dependent Variable Measures**

*Beat placement.* Beat placement was defined as measurement that quantifies the asynchronous timing between ensemble members relative to the underlying perceptual pulse of the music. Beat placement was quantified through a four-step process: (a) calculation of the downbeat onset time of each eighth note pair for the saxophone, bass, and drums, (b) calculation of the Mean Onset Time (MOS) for each downbeat of the eighth note pair, (c) calculation of the Relative Onset Time (ROT) for each downbeat of the eighth note pair, and (d) calculation of the Onset Difference Time (ODT) for each downbeat of the eighth note pair. In order to calculate the
hypothesized onset values for the upbeats in the bass and drums (mechanical norm),
the following formula was used: \( \text{Onset}_A + ((\text{Onset}_A - \text{Onset}_B)/2) \).

**Bass beat placement.** The bass beat placement was calculated by measuring
each downbeat onset time of each eighth note pair. Each onset was measured in
milliseconds (ms) using the marker tool in the Audacity 1.3.12 audio editing
software.

**Beat-upbeat ratio (BUR) value.** BUR value was defined as the temporal
proportion between two subsequent eighth notes starting on the downbeat and ending
on the upbeat. It was measured by calculating the proportion between two
consecutive eighth notes by dividing the durational value of the eighth note occurring
on the downbeat (measured in milliseconds) divided by the durational value of the
eighth note occurring on the upbeat (measured in milliseconds).

**Drummer beat placement.** The drummer beat placement was calculated by
measuring each downbeat onset time of each eighth note pair. Each onset was
measured in milliseconds (ms) using the marker tool in the Audacity 1.3.12 audio
editing software. The onset of the drummer was measured specifically using the tap
of the ride cymbal.

**Eighth note durations.** Eighth note durations consisted of the distance between
the onset of a note and its relative offset. It was calculated as offset-onset in
milliseconds (ms). Eighth note durations were measured for each downbeat and each
upbeat of eighth note pairs performed by the soloist.

**Mean Onset Time (MOT).** The mean onset time was defined as the average
onset of times played simultaneously by \( n \) players, measured in milliseconds, for each
downbeat of the eighth note pair. It was defined by the formula:
\[
\bar{w} = \frac{(w_1 + w_2 + \ldots + w_n)}{n}.
\]

**Note dynamics.** Note dynamics was defined as the relative signal energy for each individual eighth note performed. This measurement was limited to performed solo interpretations. Note dynamics was calculated utilizing MIR toolbox’s `mirrms` (root square mean) function:
\[
x_{\text{rms}} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \ldots + x_n^2}{n}}
\]

**Onsets.** Onsets were measured for each downbeat and each upbeat of eighth note pairs in the soloist as well as downbeat in the bass, and downbeat in the drums. The drums were measured using ride cymbal taps. Onsets were measured in milliseconds (ms) using the marker tool in the Audacity 1.3.12 audio editing software. In order to calculate MOS, ROT, and ODT, onsets of the downbeats of the saxophone, bass, and drums were separately labeled. The onset of the saxophone was be labeled as \(w_1\), the onset of the bass will be labeled as \(w_2\), and the onset of the drums ride cymbal will be labeled as \(w_3\).

**Onset difference time (ODT).** The onset difference time was defined as the relationship of relative onset times (ROTs) between instruments, measured in milliseconds. It was defined by the formula:
\[
d_{1,2} = v_2 - v_1, \quad d_{1,3} = v_3 - v_1 \ldots \quad d_{n-1,n} = v_n - v_{n-1}.
\]

**Relative onset time (ROT).** The relative onset time was defined as the difference between the mean onset time (MOT) and actual onset time of each
performer, measured in milliseconds. It was defined by the formula:

\[ v_1 = w_1 - \bar{w}, \quad v_2 = w_2 - \bar{w}, \quad \ldots \quad v_n = w_n - \bar{w}. \]

**Swing.** Swing was defined as the shared variance among the three factors of eighth note duration, beat placement, and note dynamics. It was calculated utilizing reliability, correlation, and regression sub-routines in the Statistical Package for Social Sciences (SPSS).

**Upbeat-beat ratio (UBR) value.** UBR value was defined as the temporal proportion between two subsequent eighth notes starting on the upbeat and ending on the downbeat. It was measured by calculating the proportion between two consecutive eighth notes by dividing the durational value of eighth note occurring on the upbeat (measured in milliseconds) divided by the durational value of the eighth note occurring on the downbeat (measured in milliseconds).

**Independent Variable Measures**

**Articulation.** Articulation was defined as the manner in which the onset of a note is started. The onset of a note can either be started with the tongue or started with an air attack (slurred). Articulation was coded for each eighth note as 1= tongued, 2= slurred.

**Intervals.** The interval was defined as the distance between two successive eighth notes. Intervals were coded as 1= minor second, 2= major second, 3= minor third, 4= perfect fourth, 5= tritone, 6= perfect fifth, 7= minor sixth, 8= major sixth, 9= minor seventh, 10= major seventh, 11= octave, 12= above an octave. The interval variable was broken into two separate variables: (a) interval preceding the measured eighth note unit, and (b) interval succeeding the measured eighth note unit.
Measure. A measure was defined as segment of time defined by a set number of beats. This study is limited to four-quarter note beats per one measure.

Melodic character. The melodic character was defined as the directional relationship between two consecutive eighth notes. It was coded as 1= ascending, 2= descending, 3= constant. The melodic character variable was broken into two separate variables: (a) melodic character preceding the measured eighth note unit, and (b) melodic character succeeding the measured eighth note unit.

Metrical placement. Metrical placement was measured for each eighth note downbeat and eighth note upbeat separately. The metrical placement was defined as the specific reference point for each of the eight equally divided eighth note subdivisions within a 4/4 measure. The downbeats were coded as 1=downbeat of beat 1, 3=downbeat of beat 2, 5=downbeat of beat 3, 7=downbeat of beat 4. The upbeats will be coded as 2= upbeat of beat 1, 4= upbeat of beat 2, 6= upbeat of beat 3, 8= upbeat of beat 4.

Performance context. The performance context was defined as either the inclusion or exclusion of accompaniment during a musical performance. Performance context was coded as 1= solo, 2= with piano, bass, and drums accompaniment.

Range. The range was defined as the distance from the lowest to the highest pitch on the solo instrument. The range was categorized into four targeted areas on the saxophone and defined by the transposed pitches as performed on the tenor saxophone. The four targeted areas were coded as: 1= low (Bb3→ F4), 2=medium (G4→ C5), 3= high (D5→ F#5), 4= altissimo (G5+).
**Tempo (beats-per-minute).** The tempo was calculated dividing the number of beats occurring in a one-minute time span by the total duration of the musical example in minutes. Time data will be gleaned from the software display upon time of analysis. The tempo was displayed as the number of quarter notes (beats) in one minute. In addition to tempo, the standard deviation of beats per minute and standard deviation as a percentage of tempo were indicated in order to support the use of the underlying beat as a temporal grid against which the melody can be measured. In order for this to occur, the standard deviation as a percentage of tempo had to be less than 8.8% (Drake & Botte, 1993).

**Underlying harmonic character.** The underlying harmonic character was defined as the measure of the specific harmonic chords that support the eighth notes being analyzed. It was measured as the function of the harmony (intended by the composer, not performer interpretations such as superimpositions) under the performed melodic line. The harmonic character was coded as 1 = tonic, 2 = dominant, 3 = subdominant, 4 = submediant, and 5 = mediant.

**Data Collection Procedures**

**Gathering of Recorded Material**

Certain musical criteria was set when selecting the material to be analyzed:

- The quality of the recording had to be clear enough in order to measure onset and offset discrimination accurately;
- The tempo was to be slower then 250 beats-per-minute (bpm) (Benadon, 2006, pp. 95-96);
The overall style was to be performed with a swing eighth-note subdivision (solos performed with a “Latin” or “funk” feel will be avoided);

- The underlying harmony of the vehicle for improvisation was functionally based. Modal and altered harmony were avoided; and

- The meter of the vehicle for improvisation was in 4/4 time.

The recorded material was based upon the solos of saxophonist Chris Potter.

Chris Potter was selected as a focal point for the following reasons:

- His performance of eighth note lines is performed in a clear manner in all registers of the saxophone (Saltzman, 2002, p. 74);

- His performances are based upon a strong rhythmical foundation rooted in the jazz tradition (Saltzman, 2002, p. 74);

- His performances contain a wide variety of applied articulations (Kluth, 2006, p. 180);

- The accessibility of performed solo interpretations meets the sample size and criteria needed for this research study;

- The accessibility of performed solos with rhythm section accompaniment based upon the same vehicles as the solo interpretations; and

- Permission was granted by Chris Potter to use all musical examples.

The musical examples were transcribed by the author with the aid of Seventh String’s Transcribe!™ version 8.10 software. The transcription was scored using MakeMusic’s Finale™ 2007 music notation software. An outside auditor verified the accuracy of the transcriptions.
To avoid difficulties due to nesting, the analysis were drawn from five separate performances. These performances included four solo interpretations: (a) *Confirmation*, (b) 26-2, (c) *It Could Happen to You*, (d) *Rhythm Changes*, and one ensemble recording (e) *Anthropology*.

**Digital Analysis for Solo Recordings**

The data designated by the variables of note duration, tempo, and beat emphasis were collected using MATLAB, created by Mathworks™ with the utilization of MIRtoolbox 1.3.3 (Lartillot, O., & Toiviainen, P., 2007; Lartillot, O., Toiviainen, P., & Eerola, T., 2008). MATLAB is a programming environment for algorithm development, data analysis, visualization, and numerical computation. MIRtoolbox is a software add-on written within MATLAB offering a specific set of functions that offers a set of computational approaches aiding in the feature extraction of audio files. Five salient algorithmic features were utilized in MIRtoolbox for the data collection of this dissertation: (a) *mirenvolve*, (b) *mirspectru*, (c) *mirpeaks*, (d) *mironsets*, and (e) *mirpitch*. 
Onsets

*Mirenvelope and Mirspectrum.* Mirenvelope measures the amplitude envelope of the signals from the audio example. In order to accomplish this task, mirspectrum was utilized. A musical sound is comprised of three fundamental frequency components: (a) fundamental frequency, (b) harmonics of the fundamental frequency, and (c) transients. (Talbot-Smith, 1999, p. 135). Mirspectrum describes all of frequency components of the audio signal. Mirenvelope divides the frequency spectrum into a default number of constituent bins, using a 100- millisecond frame size (at a sampling rate of 44100 hz), with 90 percent overlap (10 millisecond hop size), with a default frequency reassignment.

*Mirpeaks.* Once the envelope is created, mirpeaks identifies each local maximum within the envelope. The designated default values were set follows: (a) the contrast is set to 0.01, and (b) the threshold is set to 0 (p. 63). The resultant peaks indicate the onset for each perceived note in the audio sample.

*Mironset.* The onset time of each peak was calculated by choosing the “attack” parameter of the onset algorithm. With this parameter, the end of the attack phase was considered to be the peak, which detects the note onset.

*Tempo.* Autocorrelation was done on the audio samples using the following formula in order to evaluate the periodicities:

\[ R_{xx}(j) = \sum_n x_n \bar{x}_{n-j} . \]

Once the autocorrection was completed, the autocorrelation was scaled ranging from a factor of two to a factor of ten. The following plot is the autocorrelation from musical example 1.1:
The tempo algorithm requires a minimum and maximum range of tempi to be manually imputed in order to set a specific parameter. The following range tempi were used as the upper and lower bound: *Confirmation* (175 bpm-230 bpm), 26-2 (200 bpm-240 bpm), *Rhythm Changes* (175 bpm-230 bpm). In addition, a default zeropad parameter was set to 10,000 samples (p. 92). The resulting spectral analysis was compressed in time ranging from a factor of one to six (Alonso, et. All 2003).

*Mirrms (Note Dynamics).* The global energy of the audio signal was computed by calculating the root square mean:

$$x_{\text{rms}} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2}{n}}$$

**Digital Analysis for Ensemble Recordings**

Eighth note pairs were marked in sequential order. In order to digitally analyze the waveforms from the recorded material, the digital sound editor software Audacity 1.3.12 was used on an Apple™ MacBook. Each solo will be digitized at the CD quality of 44 kHz, 16 bit resolution (Ashley, 2002; Collier & Collier, 2002) and
was truncated at the onset of the first note of the soloist, providing a zero reference. Event onset times and offset times were computed for each eighth note by parsing the waveform of the recorded excerpt into its eighth note components by using the software’s marker tool. These values were then be copied onto the computer’s clipboard and transferred into a Microsoft Excel spreadsheet.

There is some degree of non-exactness because the waveforms of note onsets gradually increase. The author was consistently conservative in coding the data by choosing onsets toward the beginning of the waveform. With this method, the estimated precision was within 2-3 cycles of a waveform, or $\pm 2-5$ ms (Ashley, 2002, Benadon, 2006; Collier & Collier, 2002, Friberg & Sundström, 2002).

Caution was given to phase shifting, where the soloist moves his own metric structure away from that of the other ensemble members. If a sense that there is a systematic differentiation of the soloist’s downbeat from the ensemble, those measurements were disregarded (Collier & Collier, 2002).

**Development of Two Hypothetical Latent Variable Models**

Research into the elements of swing in jazz performance has provided strong evidence that musical structure occurs on the microrhythmic level. The data gleaned from empirical measurements of eighth note duration, beat placement, and note dynamics suggests that these factors contribute to the overall structure and functioning of swing rhythm. Each of these observable factors contains a shared variance. In this study, the shared variance among these constructs is what defines swing.

Empirical research on the microstructural aspects of jazz rhythm provides further information on specific music factors that may affect swing. These factors can
potentially be divided into two categories: soloist controlled factors and non-soloist controlled factors. The soloist-controlled factors include those that can be manipulated by the performer in any given performance. These include: (a) metrical beat placement, (b) melodic character of the phrase, (c) intervals between eighth note pairs, (d) range, and (e) articulation. The non-soloist controlled factors are those that may influence the perceptual and technical aspects of the performer. These include: (a) underlying harmony of the improvisatory vehicle, (b) tempo of the improvisatory vehicle, (c) beat placement of the bass player, and (d) beat placement of the drummer.

The review of literature in Chapter 2 provides a basis for how the three mechanical constructs of swing are influenced by these various musical factors.

Two confirmatory factor analysis (CFA) models were used in this study. Standard CFA models have three characteristics: (a) Each indicator is a continuous variable represented as having two causes: a single underlying factor that the indicator is supposed to measure and error, (b) measurement errors are independent of each other and of the factors, and (c) all associations between the factors are unanalyzed (Kline, 2005, pp. 166-167). Since the proposed models consist of continuous and categorical indicators, non-normal distributions and bias may occur. In this case, three options are available if distributions are abnormal: (a) use of a corrected normal theory method, (b) use of an estimation method that does not assume multivariate normality, or (c) the use of a normal theory method with nonparametric bootstrapping (Kline, 2005, pp. 195-197). Decisions upon the chosen method will be based on each model’s best fit. Multiple alternate but equivalent models will be utilized in this study for three reasons. First, both models reveal
different sets of data that may be important to the pedagogical application of the data.

Second, the lack of previous research in this area resulted in an absence of a priori factor categories. Without the statistical evidence of a priori categories, there is a possibility that the confirmatory factor analyses for the constructs of soloist controlled factors and non-soloist controlled factors may not provide enough statistical significance in their loadings to allow for the support of any latent variables. Third, if the musical factors are highly correlated to each other, they may have a hard time competing for shared variance. The interpretation of the latent variable will reveal itself in the factor analysis.

Both models fit the two necessary conditions in order to be identified: (a) the number of free parameters is less than or equal to the number of observations, and (b) every latent variable must have a scale (Kline, 2005, pp. 169-170). Model A contains 78 observations and 14 free parameters. Model B contains 78 observations and 56 free parameters.

Two conceptual models were then developed and refined to represent the hypothesized relationships between these factors. Both models contain a latent variable of swing is a composite of observed variables that are hypothesized to directly influence the function of swing, including eighth note duration, beat placement, and note dynamics. The difference in the two structures lies in the treatment of the musical factors. Model A hypothesizes the existence of a three latent variable structure: (a) swing, (b) soloist controlled factors, and (c) non-soloist controlled factors. The latent variable of soloist-controlled factors is hypothesized to be a composite of musical factors that can be directly manipulated by the performer,
including metrical beat placement, melodic character, intervals, articulation, and range. The latent variable of non-soloist controlled factors is hypothesized to be a composite of musical factors that cannot be directly manipulated by the performer, including underlying harmony, tempo, bass beat placement, and drummer beat placement. Although the final conclusion of the best fitting model is driven empirically, the theory behind both models is valid and similar.

**Power Analysis and Determination of Minimal Sample Size**

A power analysis was run and sample size was calculated in order to assess the fit of the two proposed structural equation models. Both were based upon the RMSEA model of fit (Kim, 2005; MacCallum, Browne, & Cai, 1996; MacCallum Browne, & Sugawara, 1996; MacCallum & Hong, 1997). Because the data will drive the best model of fit and the degrees of freedom will change according to the specific model used, a power analysis was run for both models. The data from Model A indicated that 211 units of analysis would be needed to achieve the desired power of .80, with $\alpha = .05$ and $df = 64$. The data from Model B indicated that 397 units of analysis would be needed to achieve the desired power of .80, with $\alpha = .05$ and $df = 22$. In order to err on the side of caution, the data from Model B will be used during the data gathering process in view of the fact that it yielded a higher sample size.

**Data Analysis Procedures**

The initial data from the data analysis and the measures of variables discussed above was analyzed by utilizing reliability, correlation, and regression sub-routines in the Statistical Package for Social Sciences (SPSS) as well as latent model sub-routines from the Analysis of Moment Structures (AMOS) software package.
CHAPTER FOUR

Results

In order to estimate the hypothesized fully latent variable Swing model, eighth note samples \(N=815\) from five improvised solos by Chris Potter were analyzed: (a) *Confirmation*, (b) 26-2, (c) *It Could Happen to You*, (d) *Rhythm Changes*, and (e) *Anthropology*. The latent variable of swing is a composite of observed variables that are hypothesized to directly influence the function of swing. These variables include eighth note duration, beat placement, and note dynamics. The data designated by the variables of note duration, tempo, and beat emphasis were collected using MATLAB, created by Mathworks™ with the utilization of Mirtoolbox 1.3.3. The latent variable of soloist-controlled variables was hypothesized to be a composite of musical variables that can be directly manipulated by the soloist, including metrical beat placement, melodic character, intervals, articulation, and range. The latent variable of non-soloist controlled variables is hypothesized to be a composite of musical variables that cannot be directly manipulated by the soloist, including underlying harmony, tempo, bass beat placement, and drummer beat placement. Each soloist-controlled and non-soloist controlled variables were coded accordingly as specified in Chapter 1.

The proposed model in this study could not be estimated with the method described in this study. The reality of the measurement systems in addition to the data
collection procedure did not allow for the complete data set to be run through the AMOS software. The use of Mirtoolbox proved to be problematic in isolating all aspects of the selected recordings needed to test the proposed model. In order to move forward, five simultaneous regressions and correlations were run to separately test the relationships between the first and second order factors proposed in the model. The results of the analysis will be detailed in this chapter to answer the following research questions.

**Research Questions**

**Research question one.** Do note duration, beat placement, and note dynamics define Swing? The methodology of the measurement system and data collection procedures described in this research study were found to contain limitations that prevented the statistical analysis of data collected. As a result, research question one remains to be answered. Missing data values would not allow for the estimation of the proposed model. The variable counts in Table 4.1 make clear the missing data values in the full data set.

Saxophone note dynamics were calculated with an eighth note as the unit of measurement with all solo performances \((N = 531)\) and calculated in Mirtoolbox. The note durations were calculated in Mirtoolbox \((N = 581)\) for the solo performances and in Audacity for the ensemble performances \((N = 234)\). Saxophone beat-upbeat ratio (BUR) values \((N = 375)\) were derived from the note durations that yielded consecutive eighth notes starting on the downbeat and ending on the upbeat. BUR values \((N = 375)\) were derived from the note durations that yielded consecutive eighth notes starting on the downbeat and ending on the upbeat. Upbeat-beat ratio (UBR)
values \((N = 347)\) were derived from the note durations that yielded consecutive eighth notes starting on the upbeat and ending on the downbeat. The saxophone onset times \((N = 284)\) were derived from all eighth notes in the ensemble performances using Audacity. The bass onsets \((N = 133)\), drums onsets \((N = 133)\), \(\text{ROT}_{\text{sax}} \ (N = 133)\), \(\text{ROT}_{\text{bass}} \ (N = 133)\), \(\text{ROT}_{\text{drums}} \ (N = 133)\), \(\text{ODT}_{\text{bs}} \ (N = 133)\), \(\text{ODT}_{\text{ds}} \ (N = 133)\), \(\text{ODT}_{\text{db}} \ (N = 133)\), \(\text{Bass}_{\text{Onset}} \ (N = 133)\), \(\text{Drums}_{\text{Onset}} \ (N = 133)\), and \(\text{Beat}_{\text{Placement}} \ (N = 99)\) were calculated with a quarter note as the unit of measurement with the ensemble performance.

**Research question two.** How much do the first-order factors of soloist controlled variables and non-soloist controlled variables influence the second-order factors of note duration, beat placement, and note dynamics? In order to answer research question two, the full data set was parsed into smaller subsets in order to produce complete data sets for the analysis of observed variables. Five separate
Simultaneous multiple regression procedures were calculated. Results of the regressions are presented in Table 4.2.

### Table 4.2

**Summary of the Simultaneous Regression Analyses**

<table>
<thead>
<tr>
<th>Variable</th>
<th>b</th>
<th>SE</th>
<th>β</th>
<th>p</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variables Predicting BUR values</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sax_Range</td>
<td>-.137</td>
<td>.098</td>
<td>-.106</td>
<td>.165</td>
<td>1.077</td>
</tr>
<tr>
<td>Sax_Metrical Placement</td>
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<td>.031</td>
<td>.024</td>
<td>.750</td>
<td>1.052</td>
</tr>
<tr>
<td>Underlying Harmony</td>
<td>-.041</td>
<td>.088</td>
<td>-.036</td>
<td>.636</td>
<td>1.102</td>
</tr>
<tr>
<td>Sax_Interval_Preceding</td>
<td>-.023</td>
<td>.035</td>
<td>-.053</td>
<td>.516</td>
<td>1.231</td>
</tr>
<tr>
<td>Sax_Interval_Succeeding</td>
<td>.041</td>
<td>.043</td>
<td>.075</td>
<td>.340</td>
<td>1.145</td>
</tr>
<tr>
<td>Sax_MelodicCharacter_Preceding</td>
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<td>.105</td>
<td>-.125</td>
<td>.516</td>
<td>1.250</td>
</tr>
<tr>
<td>Sax_MelodicCharacter_Succeeding</td>
<td>.161</td>
<td>.125</td>
<td>.097</td>
<td>.340</td>
<td>1.066</td>
</tr>
<tr>
<td>Sax_Articulation</td>
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<td>.155</td>
<td>-.178</td>
<td>.021</td>
<td>1.089</td>
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<td>Tempo</td>
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<td>.003</td>
<td>-.060</td>
<td>.437</td>
<td>1.097</td>
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<td><strong>Variables Predicting UBR values</strong></td>
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<td></td>
</tr>
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<td>-.074</td>
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<td>Sax_Metrical Placement</td>
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<td>.022</td>
<td>-.108</td>
<td>.156</td>
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</tr>
<tr>
<td>Underlying Harmony</td>
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<td>.062</td>
<td>.089</td>
<td>.254</td>
<td>1.127</td>
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<td>Sax_Interval_Preceding</td>
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<td>-.098</td>
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</tr>
<tr>
<td>Sax_Interval_Succeeding</td>
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<td>-.020</td>
<td>.793</td>
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<td>.089</td>
<td>.081</td>
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<td>.092</td>
<td>1.122</td>
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<td><strong>Variables Predicting Eighth Note Duration</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>Sax_Range</td>
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<td>.024</td>
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<td>1.103</td>
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<td>Sax_Metrical Placement</td>
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<td>.017</td>
<td>-.113</td>
<td>.065</td>
<td>1.045</td>
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<tr>
<td>Underlying Harmony</td>
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<td>.047</td>
<td>.081</td>
<td>.112</td>
<td>1.062</td>
</tr>
<tr>
<td>Sax_Interval_Preceding</td>
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<td>.020</td>
<td>-.162</td>
<td>.003</td>
<td>1.210</td>
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<tr>
<td>Sax_Interval_Succeeding</td>
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<td>.019</td>
<td>-.161</td>
<td>.002</td>
<td>1.048</td>
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<td>.054</td>
<td>-.108</td>
<td>.049</td>
<td>1.227</td>
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<tr>
<td>Sax_MelodicCharacter_Succeeding</td>
<td>-.008</td>
<td>.062</td>
<td>-.006</td>
<td>.898</td>
<td>1.056</td>
</tr>
<tr>
<td>Sax_Articulation</td>
<td>.091</td>
<td>.077</td>
<td>.061</td>
<td>.240</td>
<td>1.102</td>
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<tr>
<td><strong>Variables Predicting Beat Placement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sax_Range</td>
<td>.027</td>
<td>.048</td>
<td>.060</td>
<td>.570</td>
<td>1.057</td>
</tr>
<tr>
<td>Sax_Metrical_Placement</td>
<td>-.004</td>
<td>.014</td>
<td>-.032</td>
<td>.765</td>
<td>1.076</td>
</tr>
<tr>
<td>Sax_Interval_Preceding</td>
<td>-.005</td>
<td>.022</td>
<td>-.021</td>
<td>.851</td>
<td>1.157</td>
</tr>
<tr>
<td>Sax_Interval_Succeeding</td>
<td>-.017</td>
<td>.024</td>
<td>-.082</td>
<td>.459</td>
<td>1.139</td>
</tr>
</tbody>
</table>
Sax_MelodicCharacter_Preceding  -0.059  0.068  -0.107  0.356  1.252
Sax_MelodicCharacter_Succeeding -0.017  0.067  0.116  0.310  1.218
Sax_Articulation -0.058  0.074  -0.091  0.438  1.283
Tempo -0.001  0.004  -0.435  0.664  1.120

Variables Predicting Note Dynamics
Sax_Range  0.012  0.006  0.145  0.029  1.241
Sax_Metrical_Placement -0.001  0.002  -0.042  0.500  1.082
Underlying_Harmony -0.007  0.006  -0.082  0.201  1.163
Sax_Interval_Preceding  0.002  0.002  0.063  0.355  1.322
Sax_Interval_Succeeding  0.005  0.002  0.002  0.974  1.096
Sax_MelodicCharacter_Preceding  0.004  0.006  0.053  0.450  1.383
Sax_MelodicCharacter_Succeeding  0.010  0.006  0.105  0.090  1.085
Sax_Articulation  0.002  0.008  0.014  0.829  1.144
Tempo  0.002  0.000  0.437  0.000  1.177

Note. \( R^2 = 0.068 \text{ (} p = 1.8 \text{) for BUR, } R^2 = 0.128 \text{ (} p = 0.007 \text{) for UBR, } R^2 = 0.067 \text{ (} p < 0.001 \text{) for Eighth Note Duration, } R^2 = 0.052 \text{ (} p = 0.760 \text{) for Beat Placement, } R^2 = 0.223 \text{ (} p < 0.001 \text{) for Note Dynamics.}

**Subset one: Beat-upbeat ratio (BUR).** The beat-upbeat ratio (BUR) value is defined as the temporal proportion between two subsequent eighth notes starting on the downbeat and ending on the upbeat. It was measured by calculating the proportion between two consecutive eighth notes by dividing the durational value of the eighth note occurring on the downbeat (measured in milliseconds) divided by the durational value of the eighth note occurring on the upbeat (measured in milliseconds). In this study, BUR values serve to quantify the linear time-feel measurement and are referred to as “eighth note durations.” In this subset, BUR value \((N = 184)\) was simultaneously regressed on metrical beat placement, melodic character, intervals, articulation, range, underlying harmony, and tempo. The omnibus test was not statistically significant, \( R^2 = 0.068 \), \( F_{(9,174)} = 1.42 \), \( p = 1.8 \).

**Subset two: Upbeat-beat ratio (UBR).** The upbeat-beat ratio (UBR) value is defined as the temporal proportion between two subsequent eighth notes starting on the upbeat and ending on the downbeat. It was be measured by calculating the
proportion between two consecutive eighth notes by dividing the durational value of eighth note occurring on the upbeat (measured in milliseconds) divided by the durational value of the eighth note occurring on the downbeat (measured in milliseconds). In this study, UBR values serve quantify the linear time-feel measurement and are referred to as “eighth note durations.” In this subset, UBR value \( (N = 173) \) was simultaneously regressed on metrical beat placement, melodic character, intervals, articulation, range, underlying harmony, and tempo. The omnibus test was statistically significant, \( R^2 = .128, F_{(9,163)} = 2.65, p = .007 \). Metrical beat placement, melodic character, interval, articulation, range, underlying harmony, and tempo account for 12.8% of the variance in UBR. Note articulation \( (\beta = -.361, t_{(-2.99)}, p = .021) \) has a statistically significant effect on UBR. Table 4.3 provides the results from the Pearson product-moment bivariate correlation of range, metrical placement, interval, melodic character, articulation and tempo as a function of UBR.

**Subset three: Eighth note duration.** Eighth note durations are defined as the distance between the onset of a note and its relative offset. It was calculated as offset-onset in milliseconds (ms) Eighth note durations were measured for each downbeat and each upbeat of eighth note pairs performed by the soloist. In this subset, eighth note duration \( (N = 394) \) was simultaneously regressed on metrical beat placement, melodic character, intervals, articulation, range, underlying harmony, and tempo. The omnibus test was statistically significant, \( R^2 = .067, F_{(8,385)} = 3.48, p = .001 \). Metrical
Table 4.3

Summary of Intercorrelations, Means, and Standard Deviations for Scores of Range, Metrical Beat Placement, Underlying Harmony, Melodic Character, Interval, Articulation, and Tempo as a Function of UBR

<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. UBR</td>
<td>---</td>
<td>0.028</td>
<td>-0.107</td>
<td>0.061</td>
<td>-0.08</td>
<td>-0.022</td>
<td>0.033</td>
<td>0.173</td>
<td>-0.293</td>
<td>-0.149</td>
</tr>
<tr>
<td>2. Range</td>
<td>---</td>
<td>0.074</td>
<td>0.182</td>
<td>0.062</td>
<td>-0.104</td>
<td>-0.35</td>
<td>0.113</td>
<td>-0.223</td>
<td>-0.106</td>
<td></td>
</tr>
<tr>
<td>3. Metrical placement</td>
<td>---</td>
<td>0.127</td>
<td>0.027</td>
<td>-0.095</td>
<td>-0.142</td>
<td>0.053</td>
<td>0.063</td>
<td>0.017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Underlying harmony</td>
<td>---</td>
<td>0.165</td>
<td>0.023</td>
<td>0.015</td>
<td>-0.034</td>
<td>-0.016</td>
<td>-0.119</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Interval preceding</td>
<td>---</td>
<td>0.045</td>
<td>-0.412</td>
<td>0.081</td>
<td>0.083</td>
<td>-0.003</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Interval succeeding</td>
<td>---</td>
<td>0.124</td>
<td>-0.015</td>
<td>0.116</td>
<td>-0.206</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Melodic character preceding</td>
<td>---</td>
<td>-0.062</td>
<td>0.011</td>
<td>-0.154</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Melodic character succeeding</td>
<td>---</td>
<td>-0.395</td>
<td>-0.113</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Articulation</td>
<td>---</td>
<td>0.072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0. Tempo</td>
<td>M</td>
<td>1.058</td>
<td>2.76</td>
<td>4.9</td>
<td>1.97</td>
<td>3.65</td>
<td>3.94</td>
<td>1.74</td>
<td>1.62</td>
<td>1.21</td>
</tr>
<tr>
<td>SD</td>
<td>SD</td>
<td>0.662</td>
<td>0.762</td>
<td>2.22</td>
<td>0.831</td>
<td>1.873</td>
<td>1.995</td>
<td>0.804</td>
<td>0.604</td>
<td>0.441</td>
</tr>
</tbody>
</table>

*Note.* No correlations were significant beyond the .05 level.
beat placement, melodic character preceding, melodic character succeeding, interval preceding, interval succeeding, articulation, range, underlying harmony, and tempo combined to account for 6.7% of the variance in note duration. Interval preceding ($\beta = -.162, t_{(-3.00)}, p = .002$), and interval succeeding ($\beta = -.16, t_{(-3.20)}, p = .002$) had a statistically significant effect on note duration. Table 4.4 provides the results from the Pearson product-moment bivariate correlation of range, metrical placement, interval, melodic character, and articulation as a function of eighth note duration.

**Subset four: Beat placement.** Beat placement was defined as measurement that quantifies the asynchronous timing between ensemble members relative to the underlying perceptual pulse of the music. Beat placement was quantified through a four-step process: (a) calculation of the downbeat onset time of each eighth note pair for the saxophone, bass, and drums, (b) calculation of the Mean Onset Time (MOS) for each downbeat of the eighth note pair, (c) calculation of the Relative Onset Time (ROT) for each downbeat of the eighth note pair, and (d) calculation of the Onset Difference Time (ODT) for each downbeat of the eighth note pair. In order to calculate the hypothesized onset values for the upbeats in the bass and drums (mechanical norm), the following formula was used: $\text{Onset}_A + ((\text{Onset}_A - \text{Onset}_B)/2)$. In this subset, beat placement ($N = 99$) was simultaneously regressed on metrical beat placement, melodic character, intervals, articulation, range, underlying harmony, and tempo. The omnibus test was not statistically significant, $R^2 = .052, F_{(8,90)}, p = .760$. 
Table 4.4

Summary of Intercorrelations, Means, and Standard Deviations for Scores of Range, Metrical Beat Placement, Underlying Harmony Melodic Character, Interval and Articulation as a Function of Eighth Note Duration

<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Note duration</td>
<td>---</td>
<td>0.048</td>
<td>-0.086</td>
<td>0.04</td>
<td>-0.126</td>
<td>-0.154</td>
<td>-0.043</td>
<td>-0.022</td>
<td>0.052</td>
</tr>
<tr>
<td>2. Range</td>
<td>---</td>
<td>-0.011</td>
<td>0.141</td>
<td>0.03</td>
<td>-0.053</td>
<td>-0.17</td>
<td>-0.015</td>
<td>-0.182</td>
<td></td>
</tr>
<tr>
<td>3. Metrical placement</td>
<td>---</td>
<td>0.104</td>
<td>-0.036</td>
<td>-0.082</td>
<td>-0.061</td>
<td>0.085</td>
<td>-0.096</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Underlying harmony</td>
<td>---</td>
<td>0.103</td>
<td>0.102</td>
<td>-0.007</td>
<td>-0.01</td>
<td>-0.012</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Interval preceding</td>
<td>---</td>
<td>0.11</td>
<td>-0.382</td>
<td>0.022</td>
<td>-0.004</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Interval succeeding</td>
<td>---</td>
<td>-0.01</td>
<td>-0.08</td>
<td>0.114</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Melodic character preceding</td>
<td>---</td>
<td>0.014</td>
<td>-0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Melodic character succeeding</td>
<td>---</td>
<td>-0.204</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Articulation</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.723</td>
<td>2.7</td>
<td>4.57</td>
<td>1.97</td>
<td>3.74</td>
<td>3.97</td>
<td>1.71</td>
<td>1.63</td>
<td>1.47</td>
</tr>
<tr>
<td>SD</td>
<td>0.744</td>
<td>0.738</td>
<td>2.251</td>
<td>0.808</td>
<td>1.984</td>
<td>1.934</td>
<td>0.747</td>
<td>0.606</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*Note.* No correlations were significant beyond the .05 level.
A bivariate correlation was run on ROT_sax, ROT_bass, and ROT_drums using the Pearson product-moment correlation coefficient. The relationships between all three variables yielded significant results at the .001 significance level. There was a large, negative correlation between ROT_sax and ROT_bass \([r (77) = -0.612, p < .001]\), a large negative correlation between ROT_sax and ROT_drums \([r (77) = -0.523, p < .001]\), a moderate, negative correlation between ROT_bass and ROT_drums \([r (77) = -0.353, p < .001]\), and a large, negative correlation between ROT sax and average_bass-drums \([r (77) = -1.00, p < .001]\). Table 4.5 provides the results from the Pearson product-moment bivariate correlation of onset timing measures from the saxophone, bass, drums, and mean of the bass and drums.

Table 4.5

<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ROT_sax</td>
<td>---</td>
<td>-0.612**</td>
<td>-0.523**</td>
<td>-1.000**</td>
</tr>
<tr>
<td>2. ROT_bass</td>
<td></td>
<td>---</td>
<td>-0.353**</td>
<td>0.612**</td>
</tr>
<tr>
<td>3. ROT_drums</td>
<td></td>
<td></td>
<td>---</td>
<td>0.523**</td>
</tr>
<tr>
<td>4. Mean_bass_drums</td>
<td></td>
<td></td>
<td></td>
<td>---</td>
</tr>
<tr>
<td>M</td>
<td>-0.383</td>
<td>-0.023</td>
<td>0.406</td>
<td>0.191</td>
</tr>
<tr>
<td>SD</td>
<td>0.231</td>
<td>0.210</td>
<td>0.195</td>
<td>0.115</td>
</tr>
</tbody>
</table>

*Note.* **Correlation is significant at the 0.01 level (2-tailed).*

The average onset difference time between bass and drums (bass-drums) was -0.218 seconds. The average onset difference time between saxophone and bass (sax-bass) was -0.369 seconds. The average onset difference time between saxophone and drums (sax-drums) was -0.805 seconds. The average onset difference time between the saxophone and the average of the bass and drums was -0.786 seconds. It should
be noted that the onset discrimination threshold by the ear for the simultaneous playing of musical tones is approximately 20 milliseconds (Hirsh, 1959). The significant correlations challenge the claim that “the distribution of onset differences is practically random” (Rasch, 1988, p. 80).

**Subset five: Note dynamics.** Note dynamics were defined as the relative signal energy for each individual eighth note performed. This measurement was limited to performed solo interpretations. Note dynamics was calculated utilizing MIR toolbox’s `mirrms` (root square mean function. In this subset note dynamics ($N = 231$) was simultaneously regressed on metrical beat placement, melodic character, intervals, articulation, range, underlying harmony, and tempo. The omnibus test was statistically significant $R^2 = .223; F(9, 221) = 7.06, p < .001$. Metrical beat placement, melodic character preceding, melodic character succeeding, interval preceding, interval succeeding, articulation, range, underlying harmony, and tempo combined to account for 22.3% of the variance in note dynamics. Tempo ($\beta = .408, t(6427), p < .001$) had a statistically significant effect on note dynamics. Figure 4.6 provides the results from the Pearson product-moment bivariate correlation of range, metrical placement, interval, melodic character, articulation and tempo as a function of note dynamics.

**Research question three.** How much do soloist-controlled factors and non-soloist controlled influence swing? Metrical beat placement, melodic character preceding, melodic character succeeding, interval preceding, interval succeeding, articulation, range, underlying harmony, and tempo were identified as factors that may allude to the existence of a soloist-controlled latent variable and a non-soloist controlled latent variable. The identification of these factors was determined
<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Note Dynamics</td>
<td>---</td>
<td>-0.006</td>
<td>0.099</td>
<td>0.021</td>
<td>-0.056</td>
<td>0.097</td>
<td>0.01</td>
<td>0.025</td>
<td>0.432</td>
<td>-0.18</td>
</tr>
<tr>
<td>2. Articulation</td>
<td>---</td>
<td>0.054</td>
<td>0.128</td>
<td>-0.057</td>
<td>-0.165</td>
<td>-0.48</td>
<td>-0.25</td>
<td>0.063</td>
<td>-0.017</td>
<td></td>
</tr>
<tr>
<td>3. Interval preceding</td>
<td>---</td>
<td>0.029</td>
<td>-0.441</td>
<td>-0.011</td>
<td>-0.103</td>
<td>0.055</td>
<td>0.127</td>
<td>0.112</td>
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<td></td>
</tr>
<tr>
<td>4. Interval succeeding</td>
<td>---</td>
<td>-0.047</td>
<td>-0.118</td>
<td>-0.008</td>
<td>-0.057</td>
<td>0.108</td>
<td>0.164</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>5. Melodic character preceding</td>
<td>---</td>
<td>-0.075</td>
<td>0.094</td>
<td>-0.221</td>
<td>-0.098</td>
<td>-0.014</td>
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<td></td>
</tr>
<tr>
<td>6. Melodic character succeeding</td>
<td>---</td>
<td>0.119</td>
<td>-0.046</td>
<td>0.006</td>
<td>-0.111</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Metrical placement</td>
<td>---</td>
<td>0.085</td>
<td>-0.019</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Range</td>
<td>---</td>
<td>-0.217</td>
<td>0.129</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Tempo</td>
<td>---</td>
<td>-0.253</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Underlying harmony</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.179</td>
<td>1.44</td>
<td>3.95</td>
<td>4.23</td>
<td>1.74</td>
<td>1.66</td>
<td>1.52</td>
<td>2.68</td>
<td>208.71</td>
<td>1.94</td>
</tr>
<tr>
<td>SD</td>
<td>0.064</td>
<td>0.497</td>
<td>2.223</td>
<td>2.141</td>
<td>0.802</td>
<td>0.659</td>
<td>0.501</td>
<td>0.758</td>
<td>13.051</td>
<td>0.722</td>
</tr>
</tbody>
</table>

*Note.* No correlations were significant beyond the .05 level.
by previous research and logic in the realm of jazz performance. A parallel analysis (Eigenvalue Monte Carlo Simulation) and scree test was conducted using Brian O’Conner’s SPSS syntax in order to determine the statistically significant Eigenvalues of a Principal Components factor analysis (O’Connor, 2008). The test indicated that three fixed factors were appropriate to extract, as demonstrated in Figure 4.1. Table 4.7 shows the results of the initial Eigenvalues of the selected factors. The Kaiser-Meyer-Olkin (KLO) Measure of Sampling Adequacy (MSA) was .472 and indicated that the matrix fell below the recommended threshold of .5, yielding it unsuitable for factoring (see table 4.8) (Reilly, 1995).

*Figure 4.1. Scree plot drawn from parallel analysis.*
Table 4.7

*Kaider-Meyer-Olkin (KLO) Measure of Sampling Adequacy (MSA)*

<table>
<thead>
<tr>
<th>Bartlett’s Test of Sphericity</th>
<th>Approx. Chi-Square</th>
<th>.472</th>
</tr>
</thead>
<tbody>
<tr>
<td>Df</td>
<td>Sig.</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 4.8

*Raw Data Eigenvalues, & Mean & Percentile Random Data Eigenvalues*

<table>
<thead>
<tr>
<th>Root</th>
<th>Raw Data</th>
<th>Means</th>
<th>Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000000</td>
<td>1.491713</td>
<td>1.234457</td>
<td>1.303443</td>
</tr>
<tr>
<td>2.000000</td>
<td>1.397885</td>
<td>1.156065</td>
<td>1.203857</td>
</tr>
<tr>
<td>3.000000</td>
<td>1.220222</td>
<td>1.096795</td>
<td>1.138105</td>
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<td>0.510795</td>
<td>0.782545</td>
<td>0.833050</td>
</tr>
</tbody>
</table>

**Research questions four and five.** Can a hypothesized model of swing be created and statistically tested? If swing can be predicted, what are the best combinations of predictors? The methodology of data collection described in this research study did not allow for the creation and statistical testing of the hypothesized Swing Model. Chapter five discusses new data collection and measurement tools necessary to create a full data set in order to test the prescribed model.
Discussion

The purpose of this study was to create and test a hypothesized model of swing in jazz performance. The reality of the measurement systems and method of data collection proved to be problematic in deriving a data set that accounted for complete measurements for the first order factors of note duration, beat placement, and note dynamics. The inclusion of these three factors is noteworthy because it reinforces the idea that the model was founded on theory and research. However, as discussed in Chapter 2, previous empirical research in the area of jazz rhythm notably lacks statistical reliability and test validity. Although the proposed model could not be tested, the analysis of observed variables is beneficial in clarifying previous research with statistical validity. In many instances, non-significant results in this study provide an important understanding and insight into the mechanics of jazz rhythm. Table 4.9 displays prior research claims along with the statistically validated significance levels and correlations from this study. In addition, the examination of the correlations, relationships, and shared variance between these collected variables may allude to the existence of inherent latent variables. This model, although still in the exploratory stage, has potential to provide scholarly insight into the mechanics of jazz rhythm thus leading to the formulation of a pedagogy for its teaching.
Table 4.9

Comparison of Test Results with Prior Published Research

<table>
<thead>
<tr>
<th>Variables</th>
<th>Claim</th>
<th>This study</th>
<th>Accept or reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note duration and metrical placement</td>
<td>Beats 2 and 4 are generally lengthened and beats 1 and 3 are generally shortened (Rose, 1989).</td>
<td>There is no significant correlation between note duration and metrical placement ( r (394) = .088, p = .088 ).</td>
<td>Reject</td>
</tr>
<tr>
<td>Note duration and metrical placement</td>
<td>83.5% of eighth note pairs displayed longer durations of the first note (Collier &amp; Collier, 2002).</td>
<td>There is no significant correlation between note duration and metrical placement ( r (394) = .088, p = .088 ).</td>
<td>Reject</td>
</tr>
<tr>
<td>Note duration and metrical placement</td>
<td>Notes of the downbeats tended to be performed with longer duration than notes on the upbeat (Busse, 2002).</td>
<td>There is no significant correlation between note duration and metrical placement ( r (394) = .088, p = .088 ).</td>
<td>Reject</td>
</tr>
<tr>
<td>Note duration and tempo</td>
<td>As tempo increases, performers elongate note durations (Busse, 2002).</td>
<td>There is a strong, positive correlation between tempo and note duration ( r (394) = .008, p &lt; .001 ).</td>
<td>Accept</td>
</tr>
<tr>
<td>BUR and tempo</td>
<td>Swing ratio and tempo are indirectly proportional. As tempo increases, the swing ratio decreases and becomes closer to straight eighth notes (Ellis, 1991; Cholakis &amp; Parsons, 1995; Friberg &amp; Sundstrom, 2002).</td>
<td>There is no significant correlation between BUR and tempo ( r (184) = -.083, p = .265 ).</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>Swing ratio is tempo-dependent (Collier &amp; Colier, 1996).</td>
<td>There is no significant correlation between BUR and tempo ( r (184) = -.083, p = .265 ).</td>
<td>Reject</td>
</tr>
</tbody>
</table>
Swing ratio and tempo are not indirectly proportional (Collier & Collier, 1996; Benadon, 2006; Honing & de Haas, 2008).

There is no significant correlation between BUR and tempo \( [r (184) = -.083, p = .265] \).

**Reject**

**BUR and metrical placement**

Higher BUR values occur at cadential phrase endings (Benadon, 2006).

There is no significant correlation between BUR and metrical placement \( [r (184) = .562, p = .562] \).

**Reject**

**BUR and metrical placement**

BUR ratios are not uniform within a phrase. They oscillate considerably, from beat to beat (Benadon, 2006).

There is no significant correlation between BUR and metrical placement \( [r (184) = .562, p = .562] \).

**Accept**

**BUR and melodic character**

Shifts in melodic character sometimes correlate to changes in BUR values (Benadon, 2006).

There is no significant correlation between BUR and melodic character preceding \( [r (184) = -.083, p = .263] \) or melodic character succeeding \( [r (184) = .090, p = .224] \).

**Reject**

**BUR and underlying harmony**

Shifts in harmony sometimes correlate to changes in BUR values (Benadon, 2006).

There is no significant correlation between BUR and underlying harmony \( [r (184) = -.025, p = .738] \).

**Reject**

**Beat placement**

Asynchronization of nominally simultaneous tones by different instruments occurred. Tendency was for the drums to hit first, the piano to his second, and the bass to hit last (Rose, 1989).

There was a large, negative correlation between ROT_sax and ROT_bass \( [r (77) = -.612, p < .001] \), a large negative correlation between ROT_sax and ROT_drums \( [r (77) = -.523, p < .001] \) a moderate, negative correlation between ROT_bass and
Discrepancies in ensemble beat placement are contextual (Proglér, 1995). The omnibus test for beat placement was statistically insignificant, $R^2 = .052, F_{(8,90)}, p = .760$. Reject

Upbeat note placements were generally performed later than the traditional swing feel. The average BUR measurement ($N = 184$) was 1.28, placing the average upbeat .72 units earlier than the traditional triplet swing feel of 2.00. Reject

Soloists’ downbeats note placements were generally performed behind the beat at all tempi. The average onset difference time between the saxophone and the average of the bass and drums was -.786 seconds. Accept

Beat placement and tempo
Beat placement is not proportional to tempo. As tempo increases, beat placement tends to become more behind the beat (Ellis, 1991). There is no significant correlation between beat placement and tempo $[r (99) = -.023, p = .821]$. Reject

There was no relationship between upbeat note placement and tempo (Busse, 2002). There is no significant correlation between beat placement and tempo $[r (99) = -.023, p = .821]$. Accept

Note dynamics
There was only a slight tendency of upbeats to be accented (Busse, 2002). There is no significant correlation between note dynamics and metrical beat placement $[r (99) = .821, p = .821]$. Reject
CHAPTER FIVE

Summary and Conclusions

Summary

The purpose of this study was to establish a fundamental understanding of the factors that affect swing rhythm in jazz performance by creating and testing two hypothesized models for swing consistency in jazz performance. Specifically, this study sought to (a) reexamine and organize the mechanical constructs of swing rhythm, (b) explore how the constructs function dependently and independently of each other, and (c) investigate what musical factors affect those constructs through the following research questions:

1. Do note duration, beat placement, and note dynamics define swing?
2. How much do the first-order factors of soloist-controlled variables and non-soloist controlled variables influence the second-order factors of note duration, beat placement, and note dynamics?
3. How much do soloist-controlled factors and non-soloist controlled influence swing?
4. Can a hypothesized model of swing be created and statistically tested?
5. If swing can be predicted, what are the best combinations of predictors?

The mechanical constructs of jazz rhythm, including flexibility in eighth note duration (Kernfeld, 1995), asynchronisation of beat placement between ensemble
members (Benward & Wildman, 1984), and note dynamics (Schuller, 1968) have often been discussed in musicological literature and historical narratives. In addition, empirical research has been conducted in order to test aspects of eighth note duration (Benadon, 2006; Busse, 2002; Cholakis & Parsons, 1995; Collier & Collier, 2002; Poval, 1977; Rose, 1989) and asynchronization of beat placement between ensemble members (Benadon, 2006; Busse, 1997; Collier & Collier, 1996; Reinholdson, 1987; Rose, 1989). However, the claims of prior research have been misleading due to generalizations unsupported by proper statistical testing and validation.

In this study, four solo audio recordings of saxophonist Chris Potter were analyzed using the Mir toolbox add-on component to the MATLAB programming environment. One ensemble recording featuring saxophonist Chris Potter was analyzed using the Audacity audio editor. The first order factors of eighth note duration ($N = 815$), beat placement ($N = 99$), and note dynamics ($N = 531$) were measured with accuracy beyond a thousandth of a millisecond.

The reality of the measurement systems in addition to the data collection procedure did not allow for the complete data set to be run through the AMOS software. Therefore, the model proposed in this study could not be estimated. The use of Mir toolbox proved to be problematic in isolating all aspects of the selected recordings needed to test the proposed model. In order to resolve the research questions as much as possible, five simultaneous regressions and bivariate correlations were run to separately test the relationships between the first and second order factors proposed in the model.

Results from the empirical testing of the three swing constructs, note
dynamics, beat placement, and eighth note duration in relation to the second-order factors of metrical beat placement, melodic character, intervals, articulation, range, underlying harmony, and tempo shed light on their complexities in swing rhythm and further illuminates the previous research studies. Although the proposed model could not be estimated, this study offers much insight into the scope of the proposed model design.

**Pedagogical Implications**

One of the most fundamental elements of jazz performance is swing rhythm. However, it is one of the least discussed elements in because of its elusive nature. The problems stem from the difficulty of describing it in concrete terms (Lawn, 1981; Liebman, 1997).

Although the conceptualization of a model of jazz rhythm is far from completion, the results of this study provide insight into the relationships of variables pertaining to the functioning of jazz rhythm. A deeper understanding of the relationships between these variables provide insight into three specific pedagogical areas for student development:

- Prescription: the application of constructive, verbal criticism and advice toward the development of students’ rhythmic feel;
- Prevention: the ability to speak about and avoid pitfalls typically associated with developing jazz improvisers and performers; and
- Aesthetics: the ability to discuss in concrete terms aspects contributing to musical expressivity in jazz performance.
Developments on Retesting the Proposed Model

**Model reconfiguration.** An answer to the quantitative definition of swing is far from completion, but the results of the multiple regressions and correlations shed light on the relationships of the defined first and second order factors. The Kaiser-Meyer-Olkin (KLO) Measure of Sampling Adequacy (MSA) was .472 and indicated that the matrix fell below the recommended threshold of .5, yielding it unsuitable for factoring. This illuminates the concept that there is no statistically significant relationship between these particular factors. In strategizing how to analyze the existing data, a reconceptualization of the model was necessary. Foremost, the collected data did not differentiate between a solo performance and ensemble performance. There was no significant correlation between Beat-Upbeat Ratio (BUR) and Relative Onset Time (ROT) \( r = -.090 \) (99), \( p = .374 \). The independence between these two variables may demonstrate the statistical discernment between individual “swing” and ensemble “groove.” Theoretically, an individual can “swing” without the aid of an accompaniment. A saxophonist, bassist, and drummer may “swing” individually, but may not “groove” as an ensemble. Latent variables may be able to be derived from these separate measurements. The end result of the model may be to derive an empirical label for a particular performance. For the sake of this discussion, this final empirical score will be called “jazz rhythm,” while understanding that this is a label that needs to be further investigated for appropriateness and clarity. From this point, a researcher may be able to discern what an “aesthetically” pleasing performance may be for various jazz genres (i.e., swing, bebop, hard bop, etc.). Figure 5.1 demonstrates a hypothetical model for this measurement. From this point
forward, the application of multidimensional scaling techniques upon multiple performances may allow for a new conceptualization of “jazz rhythm archetypes” that may or may not fit the standard jazz narrative. This has the potential to answer the questions of whether or not the manipulation of “swing” and “groove” in the bebop genre is the same as “swing” and “groove” in the hardbop genre.

![Diagram of jazz rhythm and swing factors](image)

**Figure 5.1.** Newly conceptualized model delineating between individual swing and ensemble groove.

Consideration should also be given to the organization of the second-order factors proposed in the model. The results of this study were able to discount the assumption that the proposed second-order factors share enough variance to construct soloist-controlled and non-soloist controlled latent variables. In addition, the study
discounted the significance of many of the proposed second-order factors. A need exists to further investigate other possible second-order factors that may have an effect on the first-order factors. This may be achieved through interviews with professional performers as well as a more thorough exploration of oral histories, historical narratives, and musicological research in the field of jazz studies. Or, an entirely new strategy for carrying out a series of first order and second order factor analyses may be needed. Furthermore, a thorough reworking of the proposed method of into the nature and number of latent model classes would be needed. A possibility of one such grouping may be a separation into tonal and rhythmic/implied rhythmic elements of jazz performance.

**Perception versus mechanics.** An understanding of the relationship between the perception of jazz rhythm and the mechanics of jazz rhythm may play an important part of the advancing the understanding jazz rhythm. Early musicological discourse relating to jazz was based upon the perception of swing and groove. Perception is what guides the notion of “what swings” and what “does not swing.” However, there is no empirical support demonstrating the relationship between the perception of jazz rhythm and the mechanics of jazz rhythm. As an example, David Liebman (2003) writes, “Every jazz musician knows that ‘two’ and ‘four’ are the swinging beats and in fact it is the four that really swings, while the upbeat of four swings even more” (p. 21). However, this research study demonstrated that there is no significant relationship of metrical placement to BUR \( r (184) = .043, p = .562 \), UBR \( r (199) = -.040, p = .572 \), eighth note duration \( r (394) = -.086, p = .088 \), beat placement \( r (99) = -.004, p = .967 \), or note dynamics \( r (231) = -.060, p = .362 \). The
question remains as to what mechanical aspects of a jazz performance direct
performers’ and listeners’ ears to particular metrical placements as important swing
elements. Further investigation into the relationships between the perception and
mechanics of a jazz performance may broaden our understanding of what constitutes
a “swinging” jazz performance. In addition, parsing out perceptually “swinging”
performances from perceptually “non-swinging” performances and analyzing the
differences between the empirical data of these performances may clarify the
relationship of perception to acoustical mechanics.

**Method of data collection.** The primary setback in gathering a complete
dataset for the estimation of the proposed model was attributed to the method of data
collection. In order for a full and thorough data set to be collected, it is necessary to
measure a full performance, but be able to separate all measureable variables in order
for Mirtoolbox to accurately analyze the audio input. Given the limitations of
Mirtoolbox, there are two feasible methods for a complete data collection procedure.
The first is the use of previously released master studio recordings with particular
access to the editing and mixing windows of the digital audio workstation platform.
Manipulation of the complete track through isolation of each performer is necessary
in order to analyze individual performance attributes. The individual instrumental
tracks may then be input into Mirtoolbox to run the data analysis. The second method
is to create recordings specifically intended for research purposes. It would be
necessary for each individual ensemble member to be located in a separate isolation
booth. By controlling the type of recording environment, the researcher will simulate
a real-world performance experience, have access to a complete ensemble
performance while being able to retrieve individual ensemble members’ performance attributes.

**Contextualization: Toward the Generative Process of Jazz Performance**

Generative music can be defined as music that is (a) ever changing and (b) created by a system (Eno, 1996). Wooller, Brown, Miranda, Berry, and Diederich (2005) summarized four general interpretations of “generative music” as theorized and utilized by scholars and practitioners of algorithmic music:

- **Interactive/Behavioral:** Music resulting from a process with no discernable musical inputs, i.e., non transformational (Lippe, 1997; Rowe, 1991; & Winkler, 1998);
- **Creative/Procedural:** Music resulting from processes set in motion by the composer, such as “In C” by Terry Riley and “It’s Gonna Rain” by Steve Reich (Eno, 1996);
- **Biological/Emergent:** “Non-repeatable music” (Biles, 2002) or non-deterministic music, such as wind chimes (Dorin, 2001), as a subset of Generative Art; and
- **Linguistic/Structural:** Music created using analytic theoretical constructs that are explicit enough to generate music (Cope, 1991; Loy & Abbot, 1985); inspired by generative grammars in language and music, where generative instead refers to mathematical recursion (Chomsky, 1956; Lerdahl & Jackendoff, 1983).

The areas of interactive/behavioral, creative/procedural, and biological emergent are not of relatable interest to the future research pertaining to this study. These three
areas are in line to the sound and music programming languages based upon algorithmic manipulation. However, the area of linguistic/structural generative music provides the foundation and basis for a clear contextualization of future research endeavors.

Using Western classical music as a theoretical platform, Lerdahl and Jackendoff (1983) draw connections between the visual score, aural perception, and the unconscious musical structure inferred by the listener. This system of musical analysis, based in the cognitive sciences, moves beyond a theoretical understanding of music and provides a basis for a listener’s cognitive and perceptual capacity for musical understanding. Lerdal and Jackendoff and Sloboda (1988) outline four generative principals that parallel the study of structure in jazz performance:

- This type of methodology of musical analysis construes mental procedures under which the listener construes an unconscious understanding of music and uses it to illuminate a structural understanding of the music;
- With the aid of generative grammar, “rules” can be established utilizing a hierarchical, recursive tree structure that demonstrates the human’s cognitive ability to hear in organized patterns that ultimately shape our musical intuition;
- The construction of the metrical “rules” are based upon the examination and attention to the subtactus metrical levels; and
- The methodology assumes that the rules of grammar are “empirically verifiable or falsifiable description of some aspect of musical organization,
potentially to be tested against all available evidence from contrived
examples (Lerdahl & Jackendoff, x).

The role of structure. Jerome Bruner’s (1960) theory of the role of structure
in learning and teaching outlines the importance of structure as a fundamental concept
to understanding.

The teaching and learning of structure, rather than simply the mastery
of facts and techniques, is at the center of the classic problem of
transfer... If earlier learning is to render later learning easier, it must do
so by providing a general picture in terms of which the relations
between things encountered earlier and later are made as clear as
possible. (p. 12)

Bruner’s theoretical framework for learning explains that a learner selects and
transforms information, constructs hypotheses, and makes decisions based upon a
cognitive structure. In addition, consideration is needed for the ways in which a body
of knowledge can be structured in order to achieve and optimize student
understanding. Instruction must be organized in order for the student to easily grasp
information and designed to facilitate extrapolation of information and/or fill in the
gaps with new information. In jazz performance, the subtactus metrical level of
music expression is the performer’s treatment and interpretation of the eighth note.
David Liebman explains,

The eighth note is the substructure of jazz rhythm. It is the equivalent
of the penny to the dollar... Of course there are permutations... there
are longer rhythms and shorter rhythms, but it is essentially the eighth
note that is the currency... and to understand how to phrase the eighth
notes is crucial to having a good sense of swing. (Liebman, 1997)

Developing structure in jazz performance. According to William Russo
(1968),

The relationship [in jazz] of melody and harmony to rhythm is not
accidental, but purposeful. Both melody and harmony have a rhythmic
concomitant that cannot be ignored; conversely, rhythm cannot be spread over melody and harmony, but must rather be welded to appropriate melodic and harmonic materials. (p. 54)

An understanding of the empirical relationship between melody, harmony, and rhythm in jazz performance is essential in developing a comprehensive awareness of the structure in jazz performance. In addition, form is an important structural element that ties into rhythmic aspects of jazz: “... jazz has shown that it has three essential elements (which indeed underlie much Western music): rhythm, melody, and harmony. A fourth element is form, which is related to rhythm because it is basically the temporal organization of the music” (Martin & Waters, 2012, p. 9). Upon reaching an empirical understanding of the structure (the relationship between melody, harmony, and rhythm) in jazz performance, other considerations need to be examined to gain a more complete understanding of how the structure is affected and perceived by outside variables. These may include:

- Styles and Archtypes: the relationship between the structure of jazz and standard narrative categorization;
- Mode of Participation: the relationship of the generative (structural) processes and receptive (perceptual) processes of the listener, soloist, ensemble, and individual ensemble member;
- Mode of Engagement: the relationship and influence of structure on jazz performance, jazz improvisation, and jazz composition; and
- Educational Learning Domains: the effect of student knowledge and mental skills (cognitive), student attitude and development of feelings and emotional areas (affective), and student manual and physical skills (proficiency) on the structure of jazz.
The scope, depth, and breadth of this research reach out into many fields and disciplines, both from a jazz research standpoint and psychological standpoint. Expertise can be gleaned from “those working in psychology departments or other scientific settings, and those working in music or socio-cultural studies” (Sloboda, 1988, p. x). According to Meadows (1995), dependence on interdisciplinary methods benefits research. Theorists who utilize the “interdisciplinary methods and theories of fields such as anthropology, linguistics, literature, and sociology, will be better equipped to solve research problems that deal with the history, evolution, and related issues that have shaped jazz from its beginnings” (p. xviii). The success and profundity of understanding rely on this interdisciplinary nature. Therefore, it should be embraced. However, the interdisciplinary nature of such studies can cause inherent problems. Studies in the generative processes of music:

… draw on the ideas from linguistics, sociology, neurophysiology, acoustics, artificial intelligence and computer science, as well as psychology and music. The diversity of approach is welcome, particularly when similar ideas recur in contributions from quite different sources. It does mean, however, that several languages and perspectives rub shoulders with one another, and this sometimes makes for tensions. (Sloboda, 1988, p. x)

In addition to the difficulties of the interdisciplinary nature of such research, Sloboda (1988) outlines four other sources of inherent problems with the studies of the generative process of music.

- Cultural biases related to perception and sociology;
- Interactions between composer, performer, and listener;
- Limitations of measurement systems in the psychological sciences (i.e., the accuracy of measuring affective responses, musical transcription and notation, and mechanical parameters); and
Devising experimental controls over generative behavior (i.e., performing and modes of expression).

**Future Research Agenda**

Keeping in mind the difficulties and complexities with research in the generative process in music, the following is an agenda of research pertaining particularly to the fundamental understanding of jazz rhythm.

1. Re-testing of a model of jazz rhythm with renovated data collection methods;
2. Defining “swing archetypes:” Use of multidimensional scaling to analyze jazz rhythm styles related to the standard narrative of jazz;
3. Investigating swing performances and non-swing performances: Use of discriminant analysis to classify and investigate salient variables of swing performances;
4. On the perception of timing onsets: A data-driven analysis of the effect of asynchrony on performer perception and mechanics;
5. On the perception of timing onsets: A data-driven analysis of the effect of asynchrony on listener perception;
6. On the perception of timing onsets: A data-driven analysis examining the relationships of perception between listener and performer;
7. The relationship between performer perception and mechanical occurrence in jazz performance;
8. Investigating the empirical relationships of perceptually “swinging” jazz performances and perceptually “non-swinging” jazz performances;
9. Defining the perceptual parameters of “swinging” and “non-swinging” jazz performances: A tool for learning;

10. An empirical examination of the effects of verbal cueing on the constructs of jazz rhythm;

11. The effect aural-based learning on perceptual retention as a educational tool for learning jazz rhythm;

12. The effect of aural-based learning and notation learning on jazz rhythm learning and development;

13. The effect of musical preference on jazz rhythm development;

14. An empirical investigation into the influence of compositional techniques on the perception of swing performances;

15. Investigating the empirical disparity between reading and improvising in jazz performance; and


**Conclusion**

The nature of jazz rhythm is complex and multi-faceted. Although the proposed model was unable to be tested, this study provides a humble introduction to the intricate framework of jazz rhythm. A concrete answer to the definition of swing is far from conception; however, quantitative research in the field of jazz education has been expanded. It is the author’s hope that the groundwork provided in this dissertation aspires others to partake in jazz education research utilizing empirical means in order to unravel the elaborate nature of jazz performance and improvisation.
Additional research of this nature will allow for the building of educational theory and provide a strong, well-grounded foundation in jazz pedagogy.
References


Saltzman, J. (2002). Chris Potter’s tenor sax solo on “This Will Be.” *Downbeat, 69*(8), 74-75.


Appendix A

Musical Examples

Example 1. Confirmation

```
\[\text{G Maj7} \quad \text{E7} \quad \text{B7} \quad \text{Em7} \]
```

Example 2. Confirmation

```
\[\text{Bm7} \quad \text{E7} \]
```

Example 3. Confirmation

```
\[\text{G Maj7} \quad \text{E7} \quad \text{B7} \quad \text{Em7} \]
```

Example 4. Confirmation

```
\[\text{Dm7} \quad \text{G7} \]
```
Example 5. Confirmation

Example 6. Confirmation

Example 7. Confirmation

Example 8. Confirmation

Example 9. Confirmation
Example 10. Confirmation

Example 11. Confirmation

Example 12. Confirmation

Example 13. Confirmation

Example 14. Confirmation
Example 15. Confirmation

\[ B_{m7} \rightarrow E_7 \]

Example 16. Confirmation

\[ C_7 \rightarrow B_{m7} \]

Example 17. 26-2

\[ E_{bmin7} \rightarrow B_7 \rightarrow E_{Maj7} \rightarrow G_7 \rightarrow C_{Maj7} \]

Example 18. 26-2

\[ G_{Maj7} \rightarrow B_{b7} \rightarrow E_{bMaj7} \]

Example 19. 26-2

\[ C_{Maj7} \rightarrow E_{b7} \rightarrow A_{bMaj7} \]
Example 20. 26-2

Example 21. 26-2

Example 22. 26-2

Example 23. 26-2

Example 24. 26-2
Example 25. 26-2

Example 26. 26-2

Example 27. 26-2

Example 28. 26-2

Example 29. 26-2
Example 30. 26-2

Example 31. 26-2

Example 32. 26-2

Example 33. 26-2

Example 34. It Could Happen To You

Example 35. It Could Happen To You
Example 36. It Could Happen To You

Example 37. It Could Happen To You

Example 38. It Could Happen To You

Example 39. It Could Happen To You

Example 40. It Could Happen To You
Example 41. It Could Happen To You

Example 42. It Could Happen To You

Example 43. It Could Happen To You

Example 44. It Could Happen To You

Example 45. It Could Happen To You
Example 46. It Could Happen To You

Example 47. It Could Happen To You

Example 48. It Could Happen To You

Example 49. Rhythm Changes

Example 50. Rhythm Changes
Example 51. Rhythm Changes

Example 52. Rhythm Changes

Example 53. Rhythm Changes

Example 54. Rhythm Changes

Example 55. Rhythm Changes
Example 56. Rhythm Changes

Example 57. Anthropology

Example 58. Anthropology

Example 59. Anthropology

Example 60. Anthropology
Example 61. Anthropology

Example 62. Anthropology

Example 63. Anthropology

Example 64. Anthropology

Example 65. Anthropology
Example 66. Anthropology

Example 67. Anthropology

Example 68. Anthropology

Example 69. Anthropology
Example 70. Anthropology

Example 71. Anthropology

Example 72. Anthropology

Example 73. Anthropology

Example 74. Anthropology
Example 75. Anthropology
Appendix B

Onset Curve Plots (Mironsets)

Example 1. Confirmation

Example 2. Confirmation
Example 3. Confirmation

Example 4. Confirmation
Example 5. Confirmation

Example 6. Confirmation
Example 7. Confirmation

Example 8. Confirmation
Example 9. Confirmation

Example 10. Confirmation
Example 11. Confirmation

Example 12. Confirmation
Example 13. Confirmation

Example 14. Confirmation
Example 15. Confirmation

Example 16. Confirmation
Example 17. 26-2

Example 18. 26-2
Example 19. 26-2

Example 20. 26-2
Example 21. 26-2

Example 22. 26-2
Example 23. 26-2

Example 24. 26-2
Example 25. 26-2

![Onset curve (Envelope)](image1)

Example 26. 26-2

![Onset curve (Envelope)](image2)
Example 27. 26-2

Example 28. 26-2
Example 29. 26-2

Example 30. 26-2
Example 31. 26-2

Example 32. 26-2
Example 33. 26-2

Example 34. It Could Happen To You
Example 35. It Could Happen To You

Example 36. It Could Happen To You
Example 37. It Could Happen To You

![Graph showing an example of an onset curve (Envelope)].

Example 38. It Could Happen To You

![Graph showing another example of an onset curve (Envelope)].
Example 39. It Could Happen To You

Example 40. It Could Happen To You
Example 41. It Could Happen To You

Example 42. It Could Happen To You
Example 43. It Could Happen To You

![Graph showing Onset curve (Envelope)](image)

Example 44. It Could Happen To You

![Graph showing Onset curve (Envelope)](image)
Example 45. It Could Happen To You

Example 46. It Could Happen To You
Example 47. It Could Happen To You

Example 48. It Could Happen To You
Example 49. Rhythm Changes

Example 50. Rhythm Changes
Example 51. Rhythm Changes

Example 52. Rhythm Changes
Example 53. Rhythm Changes

Example 54. Rhythm Changes
Example 55. Rhythm Changes

![Graph](image1)

Example 56. Rhythm Changes

![Graph](image2)
Appendix C

Note Dynamics Plots (Mirpitch)

Example 1. Confirmation

Example 2. Confirmation
Example 3. Confirmation

![Graph of RMS energy for Confirmation 3]

Example 4. Confirmation

![Graph of RMS energy for Confirmation 4]
Example 5. Confirmation

![Graph showing RMS energy over time for Confirmation 5.]

Example 6. Confirmation

![Graph showing RMS energy over time for Confirmation 6.]

Example 7. Confirmation

![Graph](image1)

Example 8. Confirmation

![Graph](image2)
Example 9. Confirmation

Example 10. Confirmation
Example 11. Confirmation

Example 12. Confirmation
Example 13. Confirmation

![Graph 1](image1)

Example 14. Confirmation

![Graph 2](image2)
Example 15. Confirmation

Example 16. Confirmation
Example 17. 26-2

Example 18. 26-2
Example 19. 26-2

Example 20. 26-2
Example 21. 26-2

Example 22. 26-2
Example 23. 26-2

Example 24. 26-2
Example 25. 26-2

![Graph of RMS energy, 26,1](image)

Example 26. 26-2

![Graph of RMS energy, 26,2](image)
Example 27. 26-2

Example 28. 26-2
Example 29. 26-2

Example 30. 26-2
Example 31. 26-2

Example 32. 26-2
Example 33. 26-2

Example 34. It Could Happen To You
Example 35. It Could Happen To You

Example 36. It Could Happen To You
Example 37. It Could Happen To You

Example 38. It Could Happen To You
Example 39. It Could Happen To You

Example 40. It Could Happen To You
Example 41. It Could Happen To You

Example 42. It Could Happen To You
Example 43. It Could Happen To You

Example 44. It Could Happen To You
Example 45. It Could Happen To You

Example 46. It Could Happen To You
Example 47. It Could Happen To You

Example 48. It Could Happen To You
Example 49. Rhythm Changes

Example 50. Rhythm Changes
Example 51. Rhythm Changes

Example 52. Rhythm Changes
Example 53. Rhythm Changes

Example 54. Rhythm Changes
Example 55. Rhythm Changes

Example 56. Rhythm Changes