Preferred swing ratio in jazz as a function of tempo

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Abstract

In jazz music it is common to perform consecutive eighth notes with an alternating duration pattern of long-short. The exact duration ratio (the swing ratio) of the long-short pattern has been largely unknown. The first experiment describes measurements of the swing ratio in the ride cymbal from well-known jazz recordings. The second experiment was a production task where subjects adjusted the swing ratio of a computer generated performance to a preferred value. Both these experiments show that the swing ratio varies approximately linearly with tempo. The swing ratio can be as high as 3.5:1 at comparatively slow tempi around 120 bpm. When the tempo is fast the swing ratio reaches 1:1, that is, the eighth notes are performed evenly. The duration of the short note in the long-short pattern is approximately constant (≅100 ms) for medium to fast tempi.

Introduction

One of the most important ingredients in jazz music is the rhythm. Jazz music is supposed to "swing". One essential part of this is the rhythmic pattern sometimes called "swing eighth note pattern". It is performed by lengthening the odd eighth-notes (eighth notes on the beat) and by shortening the even eighth notes (eighth notes between the beat), thus producing consecutive long-short patterns. However, the amount of lengthening and shortening is not given in score or elsewhere and the student is often advised to learn it by listening to recordings. Gridley (1985, p.364) notes that the pattern ''falls somewhere between the tied-triplet figure and the sequence of eighth notes having identical duration.'' This means that the ratio (henceforth swing ratio) between consecutive eighth notes would be somewhere between 2:1 and 1:1. It can also be noted that the same long-short pattern occurs in many music styles, such as classical music, folk music and popular music. It is, for example, commonly used in French Baroque music where the term is *Notes Inégales* (e.g. Ferguson, 1975).

Rose (1989) measured the timing of all notes played by all instruments (piano, bass and drums) in three recordings taken from a play-along record. The compositions were examples of the jazz styles swing, jazz ballad, and latin-jazz. Among other results, he obtained mean values of the ratios between consecutive eighth notes. The swing style example was played at the tempo 132 bpm (beats or quarter notes per minute) and had an average swing ratio of 2.38:1 The instruments piano, bass and drums all performed with approximately the same swing ratio. An analysis of asynchronizations indicated that the drums were in average ahead of the other instruments, the piano was second, and the bass third.

Collier & Collier (1996) reported on some preliminary analyses of the swing ratio in different tempi. They asked three drummers to perform the pattern 3:2:1 in 9 to 11 different tempi and in two conditions: swing feel and strict triple time. The drummers played on a midi drum pad connected to a drum machine with a cymbal sound. One of the drummers performed very consistently with a clear increase of swing ratio (the 2:1 ratio in the pattern) with decreasing tempo, while in the strict triple feel he closely approximated the 2:1 relation for all tempi. The other two drummers showed different patterns both of them with a dip in the swing ratio for intermediate tempi.

The purpose of the present investigation was to further investigate the swing ratio for different tempi (1) by measuring recorded performances of well-known artists, and (2) by a production experiment where the swing ratio was adjusted by subjects in a computerized jazz trio performance.

Measurements of recorded performances

This experiment focus on the drummer's ride cymbal. It is often referred to as an important part contributing to the swing feel in ensemble playing. Another aspect was that the cymbal could easily be detected in a spectrogram since it has the highest frequency energy.

Table 1. Drummers and recording data

Drummer	Recording	Recording year
Adam Nussbaum	Aebersold Play-a-long CD: John Coltrane (JA1244D)	1983
Tony Williams	Miles Davis: My Funny Valentine, CBS, CT9106	1964
Tony Williams	Miles Davis: "Four" & More, CBS, CT9253	1964
Jack DeJohnette	Keith Jarrett, Gary Peacock & Jack DeJohnette: The Cure, ECM 1440	1990
Jack DeJohnette	Keith Jarrett, Gary Peacock & Jack DeJohnette: Standards in Norway, ECM 1542	1989
Jeff Watts	Wynton Marsalis Quartet: Live At Blues Alley, CBS 4611091	1986

The measurements were done on excerpts taken from commercial jazz recordings. Four drummers playing in four different jazz groups were selected (Table 1). All drummers could be considered as influential and well known, each with a distinguishable playing style within the jazz tradition. All recordings except the first were captured live. The two recordings with Tony Williams are both from the same concert at the New York Philharmonic Hall on February 12, 1964 (Carr, 1982).

All songs considered to be in swing style and with some part of cymbal playing were used. Most of the ballads were for this reason disregarded. From each song one excerpt was selected. These excerpts were often taken from the beginning of the first solo, i.e. when the drummer started to play a regular pattern on the cymbal. In addition, four excerpts were selected from different parts of one song of each recording. This was done to see how tempo and swing ratio differed within the same song. All the songs, the excerpts and the approximate position of the excerpts, are listed in the Appendix.

The music was transferred to a PC computer and the timing of the cymbal strokes was measured in spectrograms. The duration from one stroke on the beat to a stroke 10 to 16 beats ahead was used to estimate the tempo of the excerpt. To estimate the swing ratio, only patterns of two consecutive eighth notes followed by a stroke on the beat were used. For each excerpt, 10 such pairs of eighth notes were collected. The swing ratio of each pair was computed as the onset to onset duration of the first eighth note divided by the onset to onset duration of the second eighth note. The average standard deviation and confidence interval for these ten swing ratios were also computed. These numbers are listed in the Appendix for each excerpt.

The measurements were done on a PC computer with sound card SwellDSP V2.4 LSI PC/C31. The software used in the experiments were Swell Soundfile Editor V3.40.04 for recording and Gray Spectrogram Plotter V3.40 for making spectrograms. The excerpts were sampled with 16 bits resolution and with a sample frequency of 48 kHz. The FFT analysis in Gray used 300 Hz bandwidth and a hanning window of 6 ms.

The strokes were measured with an estimated precision of ±3 ms. In a few cases there were two strokes very close to each other (about 20 ms apart). In these cases, the loudest stroke was chosen. A possible explanation could be that the edge of the cymbal was hit before the tip of the drumstick hit the cymbal or that the drumstick was bouncing on the cymbal.

In some of the excerpts that was comparatively difficult to measure, the tempo measurement was repeated a few times in slightly different positions. The maximum span of these tempo measurements was ±3 bpm.

Swing ratio as a function of tempo

The mean swing ratio for all excerpts is plotted in the left graph in Figure 1. The general tendency is an approximately linear decrease of swing ratio with increasing tempo. A few excerpts indicate an alternative approach in slow tempi with an approximately constant swing ratio of about 2:1. The largest swing ratios are between 3 and 3.5. Note that this is more than a dotted eighth note followed by a sixteenth note. The smallest values are reaching one, that is, the eighth notes are played with equal duration.

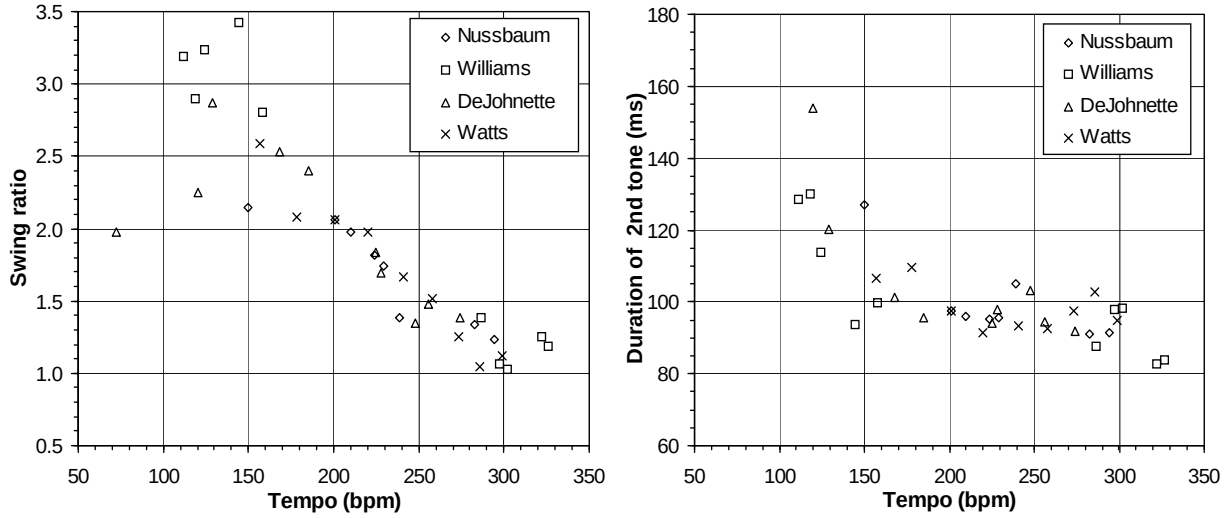

Figure 1. Mean swing ratio as a function of tempo (left) and absolute duration of second note as a function of tempo (right) for the four drummers and all excerpts. Observe that the slowest excerpt by DeJohnette (72 bpm) is outside the range of the right graph (duration of 2nd note = 416 ms).

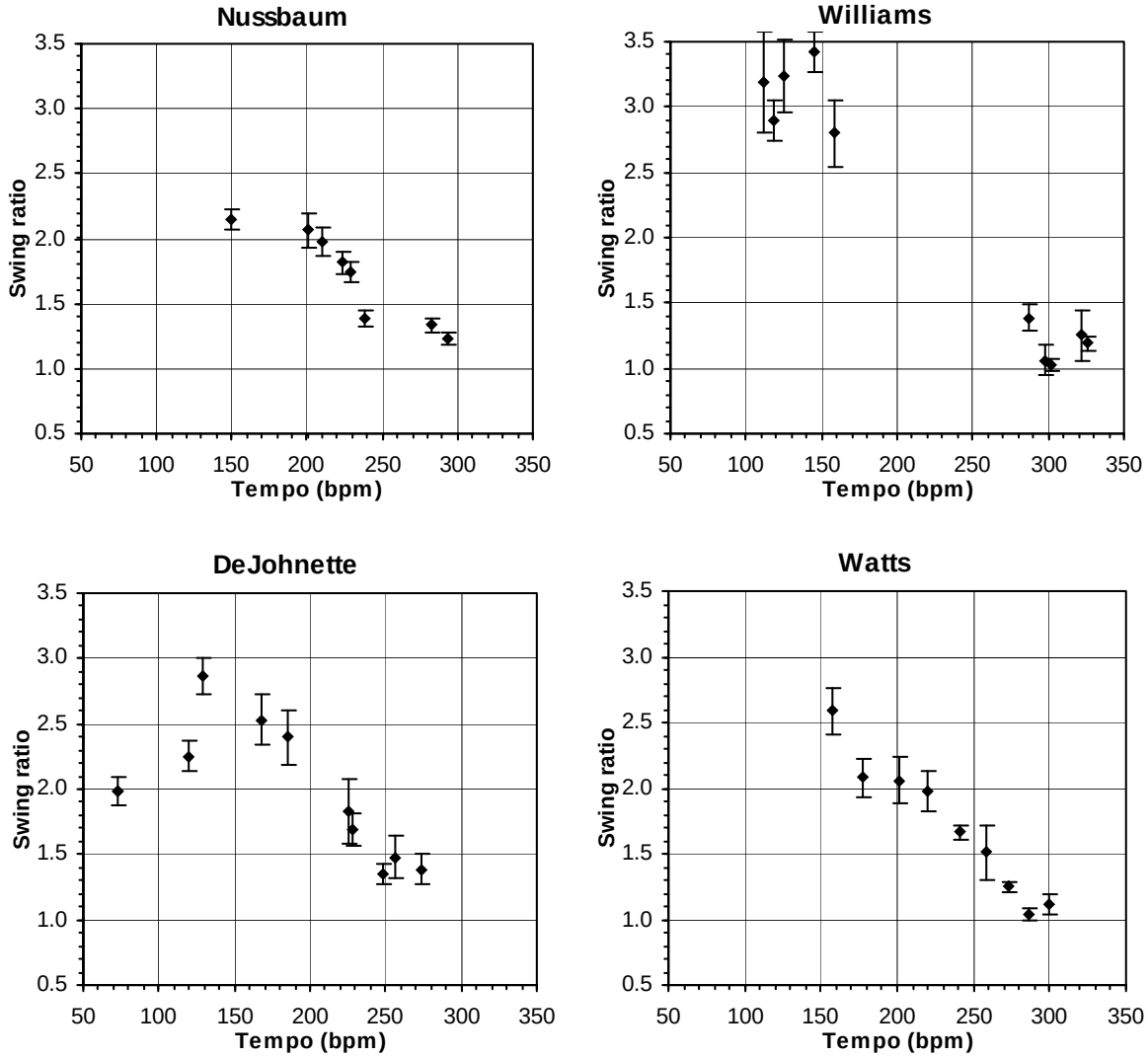

Figure 2. Swing ratio for the four drummers as a function of tempo.

The right graph in Figure 1 shows the duration of the short tone of the long-short pattern as a function of tempo. Interestingly, for medium to fast tempi (>150 bpm) the duration of the second note is approximately constant at about 100 ms. This may indicate a limit of note duration.

The swing ratios of each drummer are separated into four graphs in Figure 2. The drummers exhibit a surprisingly coherent swing ratio in view of the large differences in drumming style. Most of the differences between the drummers are found for tempi below 200 bpm. Williams had the highest ratio values for the slow excerpts. Watts may follow the same trend but there is only one sample that goes in that direction. Similarly, the ratio of Nussbaum may flatten out for slower tempi but there is only one sample there too. DeJohnette had two clear deviations from the general trend of a linear curve that indicate a deliberate change of swing ratio within the same tempo range. The difference between drummers was confirmed in a two-way anova with drummer as one factor (4), tempo as regression variable and with swing ratio as the dependent variable. Not surprisingly, the influence of tempo was highly significant ($F=186$, $p<0.0001$) but also the influence of drummer was significant ($F=4.4$, $p<0.01$). The interaction of tempo and drummer was not significant ($F=2.6$, $p<0.07$).

Included in Figure 2 are also the 95% confidence interval for each excerpt. These intervals show that the variation within each excerpt differed between drummers. Williams had the largest variation in his slow tempi and Nussbaum the smallest variation within each excerpt.

Ratio changes and tempo changes during the same song

The swing ratios in four different positions within a song are shown in Figure 3. There is very little indication of a linear change of swing ratio with the relatively small changes of tempo within each song, possibly with the exception of Nussbaum and Watts.

The tempo changes within each song are shown in Figure 4, plotted in time order. The overall trend is to continuously increase the tempo during the song and there is no example of a tempo decrease in these, however, rather few examples (cf. Collier and Collier, 1994). The difference between the first and the last tempo is in most cases remarkably large (Impressions: 12%, My Funny Val.: 16%, So What: 11%, Woody'n.: 7%, Delfeayo's Dil.: 3%).

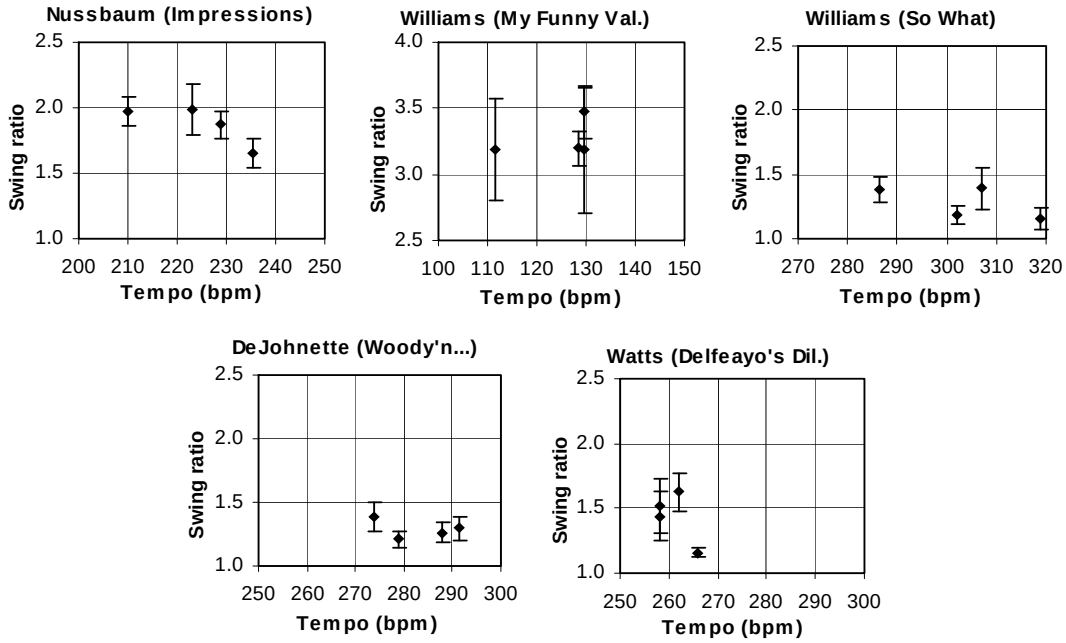

Figure 3. Examples of swing ratio as a function of tempo in four positions within one song.

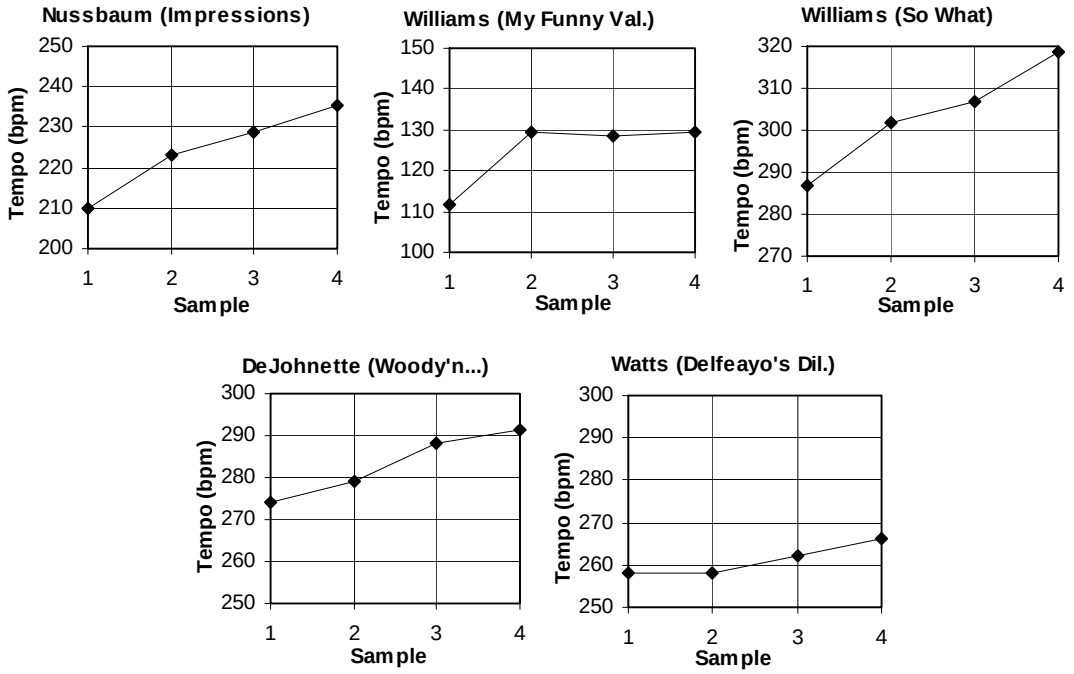

Figure 4. Tempo changes within a song. Sample 1-4 are the four different positions. See the Appendix for the approximate positions within each song.

Listeners adjustment of preferred swing ratio

Part of this experiment was first reported in Friberg et al. (1994). A total of 34 subjects participated with a varied musical background. Most of them were amateur musicians playing classical, pop or jazz music. The music example was a trio performance of the first eight bars of Charlie Parker's Yardbird Suite. It was played with electric organ, double bass and drums. All instruments were created from samples of real instruments. The swing ratio was adjusted for all instruments simultaneously so that they always played in perfect synchronization. The test was automatically run by the computer. A large scrollbar representing the swing ratio was displayed on the screen. Each time the subject moved the scrollbar the music example was played with the new ratio. The range and the end values of the scrollbar were randomly varied for each trial. The subject was asked to adjust the scrollbar to a musically optimal position. This was repeated 2 times at 5 different tempi (120, 170, 220, 270, 320 bpm). The test was implemented in the program Director Musices (Friberg, 1995) controlling a SampleCell card on a Macintosh II computer.

The resulting swing ratio averaged over subjects is shown in Figure 5. The bars indicate the 95% confidence interval for the mean value estimation. The same tendency as in the measurement of drummers is evident with an approximately linear decrease of swing ratio with increasing tempo. However, in this case the slope is smaller. A flattening of the curve may be observed for slower tempi. Again, there was only one tempo value to account for that.

Discussion

One important aspect in evaluating these data is how large deviations are perceptible. The JND (just noticeable difference) of the swing ratio was determined in a music example at the tempo 170 bpm by Friberg and Sundberg (1994); see also Friberg (1995). It was found that the average JND was about 20 %, although the individual differences were quite large. This was measured in relation to even eighth notes (ratio = 1:1). Similar results were obtained for deviations from a 2:1 pattern at a tempo of 63 patterns per minute, indicating that a 20 % difference may be a good rule of thumb for a perceptible deviation in this tempo range.

On the other hand, in psychoacoustic measurements of cyclic displacements in iso-chronous sequences, the JND was about 5% of the tone duration for tempi slower than 120 bpm (Friberg & Sundberg, 1995). For the tempo range 120 to 300 bpm the JND was constant at about 10 ms. Interestingly, the duration of second note as seen in the right graph in Figure 1, is also constant for a wide range of tempi. If

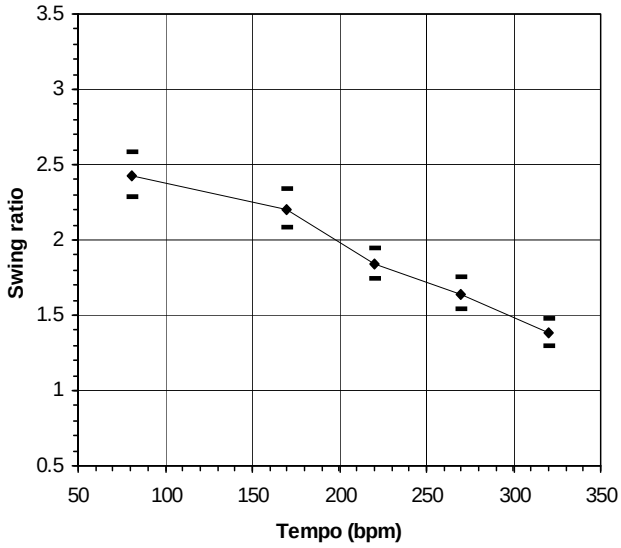

Figure 5. Listeners' preferred swing ratio as a function of tempo. The bars indicate 95% confidence intervals.

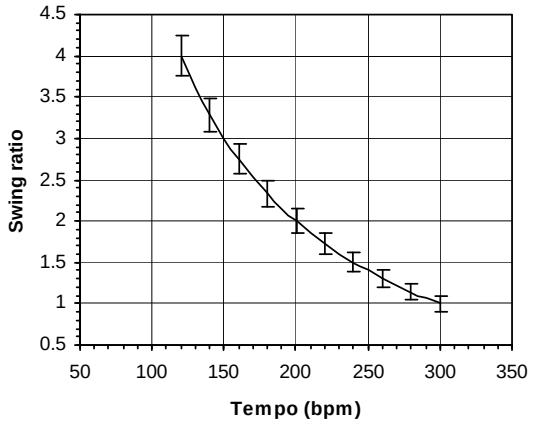

Figure 6. The curve shows the swing ratio assuming a constant 2nd note duration of 100 ms. The error bars shows the JND in swing ratio as a function of tempo, assuming a constant JND in duration of 10 ms.

we assume this lower JND of 10 ms and a constant second note duration of 100 ms we get the JND in swing ratio as shown by the error bars in Figure 6. In terms of percentages of the swing ratio the JND will be about 10% at 120 bpm and about 20% at 300 bpm. This could serve as an idea of the JND quantity. However, for a reliable estimation of the JND, it is necessary to measure it for several tempi and swing ratios.

The JND in tempo is generally smaller than the JND in displacement of tones and is about 2% over the whole tempo range measured here (Friberg & Sundberg, 1995). Thus, most changes in tempo shown in Figure 4 are clearly perceptible if the different tempi are presented next to each other. However, the time between the samples shown in Figure 4 is in general in terms of minutes. If we assume that the tempo increase is gradual, it may pass unnoticed by an untrained listener.

A direct implication of a varying swing ratio with tempo is that a swing performance is not invariant under tempo transposition, i.e. it can not be transposed in tempo by multiplying all durations with a constant factor. Similar effects of non-proportional scaling of timing patterns were found by Desain & Honing (1994) when they measured performances of the same piece at three different tempi. They used a theme and a variation by Beethoven (WoO 70) containing many repetitive metrical patterns including a 2:1

pattern of a quarter note followed by an eighth note, thus, similar to the swing type performance of long-short patterns. Repp (1994), on the other hand, found that performances of Schumann's "Träumerei" were largely invariant under tempo transposition. The "Träumerei" has, however, an entirely different character with considerably longer note durations and with no repetitive metrical patterns.

In the right graph in Figure 1, the duration of the short note reaches a limit around 80-100 ms. This range is similar to the shortest eighth notes used for a melodic line in jazz. The upper tempo limit in jazz is around 320 bpm (Collier & Collier, 1994), which corresponds to an eighth note duration of 94 ms. It is also similar to the limit of the perceptual duration of a short stimulus found by Efron (1973). He found that the shortest perceptual duration was about 130 ms, regardless of modality (auditive, visual or tactile). He also found that the electrophysiological measurements of the on and off response in the visual system of a cat exhibited a lower limit of about 50 ms.

It is interesting that among musicians it is often assumed that the swing ratio is something between 2:1 and 1:1 while in reality in slow tempi the ratio is closer to 3:1. For a musician, the 3:1 ratio is easily detected aurally by making a sixteenth note subdivision mentally. When the smallest subdivision is eighth notes, the exact ratio may not be important. However, when the soloist is playing triplets or sixteenth notes, a drummer could synchronize to a 2:1 ratio or a 3:1 ratio, respectively. This or other musical factors may explain the rather large deviations of swing ratio in the slow excerpts by Williams. Similarily, the lack of a soloist in the recordings of Nussbaum may explain the relatively small variance in his swing ratios.

Musicians often characterize Williams as being slightly ahead and to "push" the time. Watts is characterized as being less ahead and more right on the beat. Interestingly, the tempo increase is larger in the uptempo song with Williams than in the song with Watts, supporting musicians experience that a pushing drummer will increase the overall tempo. Obviously, the overall tempo is not determined solely by the drummer. Many other factors may be important for tempo variations such as if the soloist is playing before or after the beat.

Acknowledgements

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References

Carr I (1982). *Miles Davis, A Critical Biography*, London: Paladin Grafton Books.

Collier GL & Collier JL (1994). An exploration of the use of tempo in jazz, *Music perception* 11/3: 219-242.

Collier GL & Collier JL (1996). The swing rhythm in jazz. *Proc of ICMPC, Montreal, 1996*.

Desain P & Hooning H (1994). Does expressive timing in music performance scale proportionally with tempo? *Psychological Research* 56: 285-292.

Efron R (1973). An invariant characteristic of perceptual systems in the time domain. In: S Kornblum (ed.), *Attention an Performance IV,* New York and London: Academic Press, 713-736.

Ferguson H (1975). *Keyboard Interpretation*, New York & London: Oxford University Press.

Friberg A, Sundberg J & Frydén L (1994). Recent musical performance research at KTH. In: J Sundberg (ed.), *Proc of the Aarhus symposium on generative grammars for music performance 1994;* 7-12.

Friberg A & Sundberg J (1994). Just noticable difference in duration, pitch and sound level in a musical context. In: I Deliège (ed.), *Proc of 3rd Intl Conference for Music Perception and Cognition, Liège 1994;* 339-340.

Friberg A & Sundberg J (1995). Time discrimination in a monotonic, isochronous sequence, *J Acoust Soc Am* 98/5: 2524-2531.

Friberg A (1995). *A Quantitative Rule System for Musical Performance*, doctoral dissertation, Royal Institute of Technology, Sweden.

Gridley MC (1985). *Jazz Styles History & Analysis*, 2nd edition, Prentice-Hall Inc.

Repp BH (1994). Relational invariance of expressive microstructure across global tempo changes in music performance: An exploratory study, *Psychological Research* 56: 269-284.

Rose RF (1989). *An Analysis of Timing in Jazz Rhythm Section Performance* , PhD dissertation, University of Texas.

Appendix

Average data from the measurements of the recorded performances

Adam Nussbaum (in John Coltrane Play-a-long CD)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
Impressions (slow)	beginning	210	1,97	0,18	0,11
impressions (fast)	beginning	283	1,33	0,08	0,05
Giant Steps (slow)	beginning	224	1,82	0,14	0,09
Giant Steps (fast)	beginning	294	1,23	0,07	0,04
"26-2"	beginning	201	2,06	0,21	0,13
Up Against the Wall	beginning	150	2,15	0,13	0,08
Mr. Day	beginning	229	1,75	0,12	0,08
Countdown	beginning	239	1,39	0,11	0,07

Tony Williams (in Miles Davis: My Funny Valentine)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
My Funny Valentine	trumpet solo	112	3,19	0,61	0,38
All of You	sax solo	145	3,42	0,26	0,16
Stella By Starlight	trumpet solo	125	3,23	0,45	0,28
I Thought About You	sax solo	119	2,89	0,24	0,15

Tony Williams (in Miles Davis: "Four" & More)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
So What	trumpet solo	287	1,38	0,16	0,10
Walkin'	trumpet solo	322	1,25	0,32	0,20
Joshua	trumpet solo	297	1,06	0,19	0,12
Four	trumpet solo	302	1,03	0,08	0,05
Seven Steps to Heaven	sax solo	326	1,19	0,08	0,05
There is no Greater Love	piano solo	158	2,80	0,41	0,25

Jack DeJohnette (in Keith Jarrett, Gary Peacock & Jack DeJohnette: The Cure)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
Old Folks	piano solo	129	2,87	0,22	0,14
Woody'n You	piano solo, beginning	274	1,39	0,19	0,12
Golden Earrings	piano solo	168	2,53	0,31	0,19
Body and Soul	piano solo	120	2,25	0,19	0,12

Jack DeJohnette (in Keith Jarrett, Gary Peacock & Jack DeJohnette: Standards in Norway)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
All of You	piano solo	185	2,40	0,34	0,21
Just In Time	piano solo	248	1,35	0,13	0,08
Love is A Many-Splendored Thing	piano solo	228	1,69	0,20	0,13
I Hear A Rhapsody	piano solo	256	1,48	0,26	0,16
How About You	piano solo	225	1,83	0,41	0,25

Jeff Watts (in Wynton Marsalis Quartet: Live At Blues Alley)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	Conf Int 95%
Knozz-Moe-King	piano solo	274	1,25	0,06	0,04
Just Friends	trumpet solo	157	2,59	0,28	0,18
Knozz-Moe-King (Interlude), 2nd rec	trumpet solo	178	2,08	0,23	0,14
Delfeayo's Dilemma	trumpet solo, beg.	258	1,51	0,34	0,21
Chambers of Tain	trumpet solo	299	1,12	0,13	0,08
Au Privave	trumpet solo	201	2,06	0,28	0,17
Autumn Leaves	trumpet solo	286	1,04	0,08	0,05
Knozz-Moe-King (Interlude), 3rd rec	piano solo	220	1,98	0,25	0,15
Skain's Domain	trumpet solo	241	1,66	0,09	0,06

Average data from the measurements of four positions within one song

Adam Nussbaum (in John Coltrane Play-a-long CD)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
Impressions (slow)	beginning	210	1,97	0,18	0,11
Impressions (slow)	after 1 min	223	1,99	0,32	0,20
Impressions (slow)	after 3 min	229	1,87	0,17	0,11
Impressions (slow)	after 5 min	236	1,65	0,18	0,11

Tony Williams (in Miles Davis: My Funny Valentine)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
My Funny Valentine	trumpet solo	112	3,19	0,61	0,38
My Funny Valentine	sax solo, beginning	130	3,18	0,76	0,47
My Funny Valentine	sax solo, later	128	3,20	0,21	0,13
My Funny Valentine	near the end	130	3,47	0,33	0,20

Tony Williams (in Miles Davis: "Four" & More)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
So What	trumpet solo	287	1,38	0,16	0,10
So What	sax solo, beginning	302	1,18	0,11	0,07
So What	sax solo, later	307	1,39	0,26	0,16
So What	piano solo	319	1,15	0,13	0,08

Jack DeJohnette (in Keith Jarrett, Gary Peacock & Jack DeJohnette: The Cure)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	±Conf Int 95%
Woody'n You	piano solo, beginning	274	1,39	0,19	0,12
Woody'n You	piano solo, later	279	1,21	0,11	0,07
Woody'n You	bass solo, beginning	288	1,26	0,13	0,08
Woody'n You	bass solo, later	292	1,30	0,15	0,09

Jeff Watts (in Wynton Marsalis Quartet: Live At Blues Alley)

Song	Pos. in the song	Tempo (bpm)	Mean swing ratio	SD	Conf Int 95%
Delfeayo's Dilemma	trumpet solo, beg.	258	1,51	0,34	0,21
Delfeayo's Dilemma	trumpet solo, later	258	1,44	0,31	0,19
Delfeayo's Dilemma	piano solo, beginning	262	1,62	0,23	0,14
Delfeayo's Dilemma	piano solo, later	266	1,16	0,06	0,04