Conference Presentation

More Cowbell: Measuring Beat Consistency With Respect To Tempo and Metronome Variations

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"More Cowbell": Measuring Beat Consistency With Respect To Tempo And Metronome Variations

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ABSTRACT

This paper investigates the relationship between a participants' ability to maintain consistent distance between taps or strikes (Inter-Onset Interval, or IOI), when provided with varying metronome conditions and tempos. This ability, alongside traditional isochronous sequence production, represents two qualities that can be measured to express a musicians' capacity to keep time accurately.

The experiments asked participants to play along with a metronome. The timings of these taps were recorded and analysed to observe consistency and establish any effect metronome and tempo have.

The results of the experiments suggest that when the metronome is continuous, its type (Cross-Rhythmic or Mono-Rhythmic) has no significant effect on IOI. This is also true of tempo. When the metronome is removed for a number of beats, however, the results suggest this does have a significant effect on IOI consistency, and that this also has a significant relationship to tempo.

The results of this study suggest that a participants' ability to maintain a consistent IOI may not be influenced as strongly by metronomic audio information as their ability to reproduce an isochronous sequence in-phase with a metronome. This suggests that consistent IOIs and traditional, in-phase timekeeping are not as closely linked as could be expected.

1 INTRODUCTION

This study forms the initial stage of a broader study that explores timekeeping accuracy and the factors that can affect it. It is intended that, through several phases of testing and analysis, a programme of study can be established to improve timekeeping accuracy and increase that rate of improvement. It is anticipated that this programme of study will eventually become an e-learning and mobile device based mechanism, suitable for multiple instrument families, and over a range of musical abilities and experiences. Understanding the link between a musician's ability to maintain a consistent level of accuracy, and the amount of timing information provided to the musician, is anticipated to be an important factor in determining how an adaptive system of tuition could best be designed.

This paper investigates the relationship between differing states of metronomic audio stimuli, in the role of a click track, and the effect that the stimuli may have on the participants' ability to maintain a consistent Inter-Onset Interval (IOI), by either tapping a sensor pad or striking a cowbell along with the metronome. This interval (also referred to as Inter Beat Interval, or IBI) describes the amount of time between the beginning of a note in a sequence and the beginning of the next note in that sequence.

Throughout the paper, some terms and phrases are used to describe the interaction of the participants with the test procedure. *Tempo* describes the regulated speed or rate at which the metronome is being replayed or the speed of the participants isochronous responses. The *metronome* or *click* for both test experiments is a digitally-produced sequence of time markers, set at a regular rate. Test participants were asked to tap a sensor pad in Experiment 1 and strike a cowbell for Experiment 2. The terms *play along* and t*ap along* are used to describe this interaction.

In this study, the results of two separate experiments are reported and the discussed, comparing the IOIs of the metronome (*expected* IOI, or e-IOI) and the IOIs of the participant (*performed* IOI, or p-IOI). Taking averages of these intervals over a selected number of beats for the purpose of comparison across experimental conditions, allows conclusions to be drawn as to the influence of tempo, rhythmic information and absence of the metronome on the participants' ability to sustain a consistent p-IOI.

Therefore, we determine e-IOI duration in seconds based upon the tempo of the metronome in BPM

$$\tau_{BPM} = \frac{60}{BPM} \qquad (1)$$

When recording p-IOI in our experimental work, each participant's tap or strike is recorded relative to the beginning of the metronome sequence, forming an array of times $X = x_1, x_2 \ldots x_n$, where $x \in \mathbb{R}_{>0}$. From this, the mean p-IOI can be calculated

$$\bar{\Delta} = \frac{x_n}{n} \qquad (2)$$

Finally, a normalised mean p-IOI is determined relative to the e-IOI at the tempo concerned

$$\bar{\Delta}_{BPM} = \left| 1 - \frac{\bar{\Delta}}{\tau_{BPM}} \right| \qquad (3)$$

The experiments in this study are concerned only with IOI. As such, the effect of the differing metronome states are only discussed in terms of their influence on participants p-IOIs and not in terms of their influence on participants ability to tap accurately in time with the beats, or e-IOIs.

2 LITERATURE REVIEW

There is a solid body of work in existence that employs experiments that measure the ability of individuals to keep time. For instance, Repp [1] investigates the possible effect that a deliberately distracting and asynchronous audio-timing sequence can have on participants who are attempting to tap at a conflicting tempo. Whilst more concerned with the effect that the auditory distractor may have on self-paced tapping, the experiments in the study also examine the effect that these distractors may have on tapping with isochronous sequences, and with and without auditory feedback. The results of this study suggest that auditory distractors have an effect on timekeeping accuracy. In particular, the effect would seem more pronounced when the auditory distractor is in competition with a reference or target sequence. Repp's work provides a starting point for the design of the test methodology included in the following two experiments that are the focus of this paper. Auditory feedback will be included and the effect of increased audio information on performed IOI will be recorded.

The selection of the various tempos used throughout both experiments has been influenced by studies in the area of preferred tempo and research that has investigated possible physical limitations to sensorimotor synchronisation. Moelants [2] considers the preferred (or perhaps, optimal or natural) tempo for humans, suggesting that whilst 100 BPM (Beats Per Minute) has been regarded as the *de facto* preferred tempo, it should be significantly higher – in the order of 120 BPM, leading to an ideal e-IOI of 500 ms. Moelants has related this preferred tempo to natural walking speed, variability in finger tapping experiments and the natural speed of repetitive applause. Whilst there may be potential variability within these findings (natural walking speed may differ according to age or gender, for example), this research provides a focal point for tempo selection for the experiments in this paper. Moelants also notes a potential correlation between preferred tempo and 'octave' relationships of tempo i.e. a connection between 120 BPM and the factors or multiples thereof. As Moelants states "*the 'octave' 81-162 bpm (370-740 ms) is found as optimum*" [2].

This 'harmonic' relationship between tempo preference and sub-divisions or multiples of 120 BPM may go some way to support the findings of Grondin, Meilleur-Wells & Lachance [3]. Their research suggests, in general terms, that an interval of around 1.18 seconds marks '*the point at which explicit counting improves performance*' [3], although, this estimation of a tipping point in human timing processes may be alterable. Perhaps the inclusion of increased rhythmic information may 'enforce' explicit counting on participants in an isochronous interval reproduction test.

As with many tests that require physical interaction from participants, there is the likelihood of improvement through repetition and practice. Madison, Karempala, Ullén & Holm [4] established that there may be an effect on the variability of timekeeping of participants in a tapping experiment through practice. Their findings show that practice can decrease the variability of timekeeping, both locally and general drift over entire sequences, although there is no suggestion of the long-term effects on an individual's timekeeping. The study suggests that this decrease in variability stops after approximately the first hour of practice, regardless of the type of task the participant is asked to perform or the type of sensory feedback the participant is given. The authors indicate that these results likely relate to motor implementation rather than cognitive timing processes. Overall, Madison *et al.* suggest that practice can have an effect on the variability between IOI, but less so on drift. They propose that this effect is largely connected with the improvement and increased familiarity of motor response, and that practice is unlikely to have affected the intrinsic timing abilities of the participants.

Of course, the ostensive purpose, from a musical standpoint, of timekeeping is to enable musicians to interact in some form of meaningful sense. As defined by Clayton, Sager & Will [5], entrainment is '*...a phenomenon in which two or more independent rhythmic processes synchronize with each other*'. Studies of entrainment are numerous, and this phenomenon is likely to have an effect on a participants' ability to synchronise with the metronome, both in terms of marking expected pulses and in maintaining a consistent p-IOI. However, the interaction of participants in a group test may alter the intensity of this effect.

3. EXPERIMENT 1

3.1 Aims & Objectives

Experiment 1 was intended to investigate a link between consistency of p-IOI and the amount of audio rhythmic information provided to participants. The experiment was also designed to examine the effect of this change of rhythmic information over differing tempos. It was expected that tempo would influence the consistency of p-IOI and that the increased rhythmic information in the Cross-rhythmic metronome would improve consistency of participants' p-IOI.

3.2 Participants

This experiment was performed by 22 participants (20 male, 2 female), with an average age of 37. 16 of the participants identified themselves as musicians (regularly played an instrument for 5 years or more). Musicians and non-musicians were not segregated in any way for this experiment. Convenience sampling was used to select the participants for this experiment. The participants were a mixture of Music Technology, Sound Technology and TV Production Technology students from the University, with additional participants from the researcher's network of contacts.

3.3 Stimuli

The experiment used 6 audio clips (3 Cross-rhythmic, 3 Mono-rhythmic) at 3 differing tempos (60 BPM, 120 BPM and 180 BPM). These 6 audio clips were played at random. The audio clips were then repeated, again in a random order. Therefore, each participant would be played a total of 12 audio clips.

The Mono-rhythmic metronome type consisted of a simple isochronous pattern, using a stock audio sample provided in the Logic Pro X software. The Cross-rhythmic metronome type added a semiquaver pattern (at a higher pitch) and a syncopated pattern (at a lower pitch).

3.4 Equipment

The audio clips for this experiment used a stock cowbell sample sourced from Logic Pro X (v10.2.4) software. This sample was used as the basis for the Cross-rhythmic and Mono-rhythmic audio clips. Additional audio information was added to the Cross-rhythmic audio clips using various stock samples sourced from Logic Pro X software. The additional audio information consisted of two extra instrument strands, one of which was higher in pitch than the cowbell and one that was lower in pitch. These pitches were selected to provide a wide frequency range in the additional audio information.

The participants listened to the stimuli through Sennheiser HD 201 headphones and were asked to tap a sensor pad in time with the metronome. The sensor pad was constructed from a 3 mm thick wooden disk, soundproofing foam and a 27 mm Piezo sensor. The Piezo sensor was connected to an Alesis Trigger I/O, which in turn was connected via USB to MAX/MSP (v.6.1). The audio clips and auditory feedback for participants' taps were hosted in the Max patch for the experiment. The experiment took place in a well-lit testing room, with only the researcher and participant present.

Figure 1: A Participant from Experiment 1

3.5 Procedure

The participants were asked to tap a sensor pad in time with 12 audio clips, each consisting of 32 beats. There were 2 differing conditions to the audio clips; tempo and rhythmic information i.e. Mono-rhythmic or Cross-rhythmic. Participants were randomly played either a Mono-rhythmic or Cross-rhythmic audio clip at one of the 3 tempos. Once the complete set of 6 audio clips had been played, the process was repeated (again, in a random order).

Participants were given a 4 beat introduction to each audio clip. The first 4 and last 4 taps were discounted from the analysis of the results. The tapping data from each participant was recorded through the MAX/MSP patch and saved as a plain text for easy import and analysis. Where actual taps fell within a given range of the expected beats (50% of the nearest expected Inter Onset Interval), they were assigned as the attempted tap for the nearest expected beat. Retriggers that fell within a given range ($\leq$ 80 ms) were discounted from the results, and only the first (or main) tap was counted and assigned. The figures discussed are normalised distance values, where 0 would represent the participant consistently maintaining a perfect time interval. 1 would indicate a participant is either a beat ahead or a beat behind the expected interval.

3.6 Results & Analysis

The results of Experiment 1 can be categorised into two separate phases, with two separate conditions: Tempo and Metronome type, analysed using a two-way ANOVA with repeated measures for statistical significance.

In terms of the factor of *tempo*, Mauchly's Test of Sphericity indicated that the assumption of Sphericity should be rejected, $\chi^2(2) = 10.720$, $p < 0.05$. Subsequently, the ANOVA with a Greenhouse-Geisser correction determined that there is no significant effect of *tempo* upon mean IOI measure ($F(1.257, 0.001) = 0.019$, $p > 0.05$).

With regards to the *metronome type*, since there are only two conditions of this variable, Sphericity is not meaningfully testable and so is assumed. To this extent, the ANOVA determined that there is no significant effect of *metronome type* upon mean IOI measure ($F(1, 0.001) = 0.913$, $p > 0.05$).
In terms of the factor of the *interaction* between *tempo* and *metronome type*, Mauchly's Test of Sphericity indicated that the assumption of Sphericity should be rejected, $\chi^2(2) = 7.615$, $p < 0.05$. Subsequently, the ANOVA with a Greenhouse-Geisser correction determined that there is no significant interaction effect of *tempo and metronome type* upon mean IOI measure ($F(1.361, 0.002) = 1.453$, $p > 0.05$).

Table 1: First attempt - Mean distance from ideal IOI (normalised)

Tempo (BPM)	Cross-Rhythmic Metronome	Mono-Rhythmic Metronome
60	0.0212	0.0257
120	0.0284	0.0202
180	0.0268	0.0223

Table 2: Second attempt - Mean distance from ideal IOI (normalised)

Tempo (BPM)	Cross-Rhythmic Metronome	Mono-Rhythmic Metronome
60	0.0237	0.0230
120	0.0212	0.0248
180	0.0240	0.0213

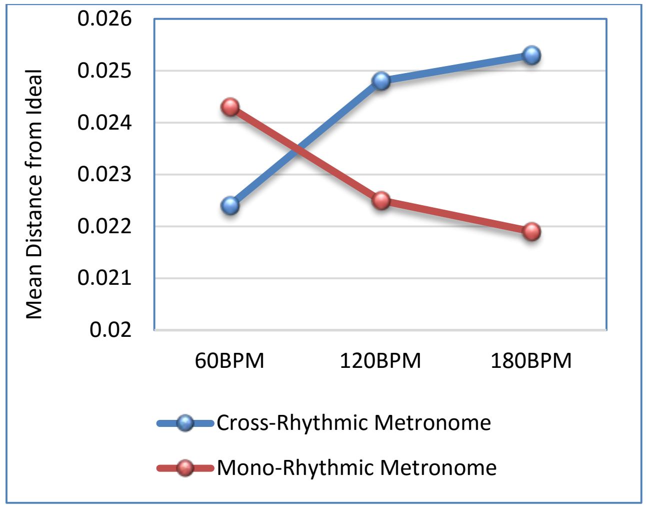

Figure 2: Mean distance from ideal IOI (normalised)

Based on evaluation of the results from this experiment, the following statements can be made:

- *There was no statistical significance in the change of IOI between metronome type;*

- *There was no statistical significance in the change of IOI over tempo.*

3.7 Limitations

In essence, this experiment required participants to complete the same randomised test on two occasions. As such, no practice or trial run was given to the participants before they commenced testing for the first time. Therefore, the results of each testing sequence are treated separately to account for any training effect that may have skewed an overall or averaged result. If this test procedure were repeated for further experiments, in may be beneficial to include a practice attempt before each test phase.
As Madison et al. [4] suggest, tempos with an IOI shorter in duration than 500 ms may prove more difficult to tap in time with for untrained participants or non-musicians. One of the tempos used in the test procedure resulted in an expected IOI of 333 ms, and this may account for a greater inconsistency of p-IOI in the untrained participants tested.
The test procedure for this experiment allowed for collection of IOI information and comparative timing information (timing of performed tap compared to the timing of the expected pulse). The results of participants who tapped alternate pulses or provided less than 50% of expected IOI information were discounted.

4. EXPERIMENT 2

4.1 Aims & Objectives

Experiment 2 was intended to investigate the effect on consistency of participants' IOI when provided with an intermittent metronome. The experiment also intended to measure and investigate any noticeable entrainment effect that group playing might have on the consistency of participants' p-IOI. Consequently, the experiment required participants to strike a cowbell with a drumstick to allow for interaction between the participants in the group phase of testing. Based upon the findings of Fuji [6] and others, the use of a drumstick strike instead of a finger or hand tapping exercise was included to reduce any increased natural latency that might occur.

4.2 Participants

This experiment was undertaken by a total of 16 participants (10 male, 6 female) with a mean age of 21.7 of the participants identified themselves as musicians (regularly played an instrument for 5 years or more). Musicians and non-musicians were not segregated in any way for this experiment. Convenience sampling was used to select the participants for this experiment. The participants were a mixture of Music Technology, Sound Technology and TV Production Technology students from the University.

4.3 Stimuli

This experiment used 4 audio clips at 4 differing tempos (80 BPM, 100 BPM, 120 BPM & 160 BPM). The audio clip of 100 BPM was used a practice attempt by all participants – the remaining 3 audio clips were replayed at random and are the focus of the subsequent analysis of this experiment.

4.4 Equipment

The metronome for experiment 2 used a stock cowbell sample sourced from Apple's Logic Pro X (v10.2.4). The participants heard the stimuli through two JBL SRX 715 speakers (powered by a Crown 3000 stereo amplifier). The audio feed for the amp was provided directly from the MacPro headphone output (via the 3.5mm headphone output). The audio clips for the experiment were hosted in the Max patch for the experiment. Participants were asked to tap a cowbell with a drumstick. The cowbell was fitted with a Piezo sensor that was in turn connected to an Alesis Trigger I/O. This trigger-to-MIDI converter was connected via USB to MAX/MSP (v.6.1). The experiment took place in the Television studio on the University campus, providing an acoustically controlled environment.

Figure 3: Participants from the group phase of Experiment 2

4.5 Procedure

The participants were asked to strike a cowbell in time with 3 audio clips, each lasting 100 beats. The clips were played at random and at 3 different tempos (80 BPM, 120 BPM & 160 BPM). Participants were given a practice attempt before the experiment began at the 100 BPM tempo condition. After 48 beats (not including the 4 beat introduction) the metronome fell silent and the participants were asked to continue striking the cowbell at the same tempo. After 16 beats, the metronome was re-introduced and the participants were asked to continue to try and keep time with the metronome.

The first 8 and last 8 beats were discounted from the analysis of the results. The tapping data from each participant was recorded through the MAX/MSP patch and saved as a plain text file for easy import and analysis. Where actual taps fell within a given range of the expected beats (50% of the nearest expected Inter Onset Interval), they were assigned as the attempted tap for the nearest expected beat. Retriggers that fell within a given range ($\leq$ 80 ms) were discounted from the results, and the first (or main) tap was counted and assigned.

4.6 Results & Analysis

The results of Experiment 2 can be categorised into three separate phases: *With Metronome; Metronome Withdrawn; and Metronome Reintroduced* with two separate conditions. Data collected was subsequently analysed for statistical significance using a two-way ANOVA with repeated measures.

In terms of the factor of *tempo*, Mauchly's Test of Sphericity indicated that the assumption of Sphericity had not been violated, $\chi^2(2) = 0.616$, $p = 0.753$. Subsequently, the ANOVA test determined that participants' mean IOI measures differed statistically significantly between the three tempos tested ($F(2, 0.009) = 7.530$, $p < 0.003$). Post-hoc tests using the Bonferroni correction indicated that there are statistically significant differences in mean IOI measures between tempos of 80 BPM and 120 BPM ($p < 0.01$) but not between tempos of 80 BPM and 160 BPM ($p = 0.367$) or tempos of 120 BPM and 160 BPM ($p = 0.176$).

In terms of the factor of *stage of test (metronome condition)*, Mauchly's Test of Sphericity indicated that the assumption of

Sphericity had not been violated, $\chi^2(2) = 5.96$, $p = 0.51$. Subsequently, ANOVA testing determined that participants' mean IOI measures differed statistically significantly between the three tempos tested ($F(2, 0.015) = 21.662$, $p < 0.00001$). Post-hoc tests using the Bonferroni correction indicated that there are statistically significant differences in mean IOI measures between all combinations of metronome condition, specifically: the conditions of *metronome present* and *metronome removed* ($p < 0.001$); between *metronome present* and *metronome reinstated* ($p < 0.01$); and between metronome removed and metronome resumed ($p < 0.02$).

In terms of the *interaction* between the *tempo* and *stage of test* factors Mauchly's Test of Sphericity indicated that the assumption of Sphericity should be rejected, $\chi^2(9) = 0.059$, $p < 0.05$. Subsequently, the ANOVA test with a Greenhouse-Geisser correction determined that the interaction between tempo and stage of test (metronome condition) does not significantly effect mean IOI measures ($F(1.899, 0.030) = 2.992$, $p > 0.05$).

Table 3: Experiment 2 - Mean distance from ideal IOI (normalised)

Tempo (BPM)	With Metronome	Metronome Withdrawn	Metronome Reintroduced
80	0.0032	0.0217	0.0051
120	0.00000757	0.0109	0.0081
160	0.0007	0.0254	0.0123

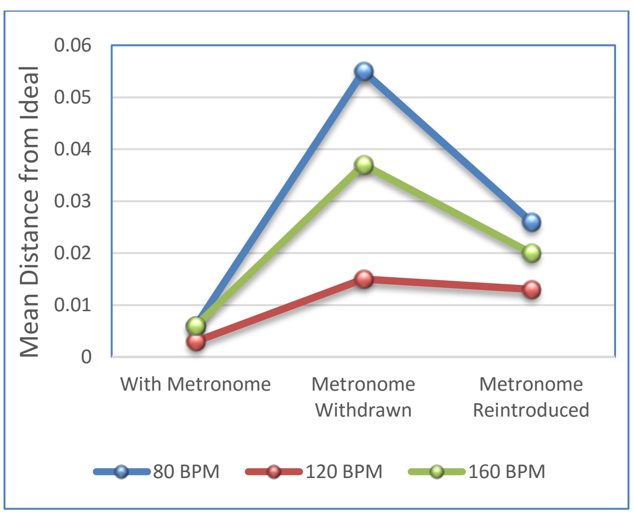

Figure 5: Mean distance from ideal IOI (normalised)

Based on evaluation of the results from this experiment, the following statements can be made:

- *There was statistical significance in the change of IOI between test conditions;*
- *There was statistical significance in the change of IOI over tempo;*
- *There was no statistical significance in the length of IOI between tempo and presence of metronome.*

4.7 Limitations

As outlined earlier, this experiment was initially designed to test two participation conditions and their possible effect upon IOI: individual and group participation. Unfortunately, the resonant frequencies from multiple participants resulted in retriggers that obscured the group data. It was also noted that the trigger to MIDI interface and interconnections struggled to process multiple inputs at near-simultaneous occurrences.

The data from the individual test phase was unaffected and produced interpretable results, however the group phase did not provide useable results, although anecdotal observations of the group test phase suggest a potential impact on entrainment.

5 CONCLUSIONS

The results from Experiment 1 suggest there is no link between p-IOI and the type of metronomic or rhythmic information provided to the participant. However, this does not reflect upon any impact that information may have on a participants' ability to accurately stay in time with a metronome. It is possible that a participant may maintain a p-IOI consistent with the e-IOI but be in between with the metronome pulses i.e. 'out of time'. These results also suggest that there is no discernible effect on p-IOI by increasing or decreasing the tempo (within the tempo bands of the experiment). Repp [7] reports a noticeable drop in the accuracy of participants' timekeeping accuracy when asked to produce anti-phase p-IOIs with intervals of less than 350 ms (approx. 171 BPM). Production of in-phase intervals yields a higher limit of 150-200 ms (300-400 BPM). This is not necessarily reflected in the p-IOI's of participants in this experiment. P-IOI and timekeeping accuracy might not be mutually inclusive.

The test process of experiment 1 provided unbroken rhythmic information, even if the content differed from one condition to the other. Experiment 2 investigated the effect that removing the metronome might have on a participant's ability to maintain a p-IOI consistent with that of the e-IOI of the metronome. The results show that there was a definite decrease in the consistency of p-IOI when the metronome was removed. It also suggests that the re-introduction of the metronome does not immediately reinstate the consistency of p-IOI that was present in the condition before its removal. As the average p-IOI consistency is at its worst at the slowest tempo, it is another indication that p-IOI and timekeeping accuracy (in terms of matching isochronous metronomic information) are not necessarily linked.

6 FUTURE WORK

These experiments represent the first exploration of a wider subject theme. The results question the link between any improvement to p-IOI and any increase in rhythmic information, although there would appear to be an effect on the p-IOI when a metronome is removed completely. Investigation of this relationship and any further link between a participants' ability to match a series of isochronous intervals may shape the considerations for the next stages of testing. Forthcoming experiments will use similar tests but various instrument families, investigating the potential differences in cognitive and physical requirements of those instruments and how the differing requirements may affect the consistency of p-IOIs. The experiments in this paper tested musicians and non-musicians, as it was assumed that all participants would be familiar with the physical requirements for tapping or striking an object. As these experiments are expanded to other instruments, it may be necessary to test participants with some familiarity with the required techniques to play an instrument from the chosen instrument family. The work of Jacks, Stockman & McPherson [8] has already begun an investigation of latency in digital instrumentation; it will be interesting to observe the effect natural latency may have on the timekeeping and consistency of musicians playing traditional instruments.

Further work may also include additional investigation of the effect metronome type and rhythmic information could have on timekeeping accuracy of participants; both in an introductory tapping test and throughout instrument families. This would involve a concurrent path of investigation, exploring the ability of participants to accurately tap or sound a note at the expected interval and may not necessarily be connected to the consistency of the p-IOIs.

7 ACKNOWLEDGEMENTS

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