An Analysis and Replication of Dynamic Attending Theory

Kevin Kwok-Ho Liu

University of California Berkeley

Author Note

This paper was completed as the final project for Music 108 (Perception and Cognition in Music) course at UC Berkeley. Original data sets, full surveys, and associated audio files/musical sequences are available online at <https://github.com/kevinliu002/music108>. Direct links to Jupyter notebooks are here:

**Introduction**

If you are like most people, you likely have some sort of routine you do on a daily basis. Whether it be your morning regime of getting out of bed, brushing your teeth, making breakfast, and hopping in your car for work, or simply the process of washing, drying, and folding your clothes, these routines seem to help us get our work done in an efficient manner. There is a feeling of being in sync or on schedule as we expect one process to come after the other, allowing a person to perform their best. Even so, humans do not pay attention equally at all times, with attention spans rising and falling in line with expectations. A person becomes attentive when the coffee is done brewing, but less alert when simply waiting for the toast to finish cooking. On the same note, when something becomes out of sync, or is unexpected, performance appears to decline, and a person’s expectations are confused.

This phenomenon of attention being periodic is not new, with scientists like Carl Seashore first suggesting that accurate anticipations help facilitate a person’s attention in the 1930s which supports the theory that humans are biologically predisposed to “minimize expenditure of energy” through “optimi[zation] of arousal levels” (Huron, 2006). Most notable was the work of Mari Riess Jones where she developed dynamic attending theory (also known as the temporal perspective model) to explain how an individual’s attention is strongest at certain metric positions, and that a person’s attention, is periodic, just like a sine wave. Successful synchronization with an external event such as a constant rhythm also allows an individual to entrain his or her expectations and be better prepared to analyze a stimulus (Oxford Handbook of Musical Psychology).

In 2002, Jones and colleagues formally put this theory of dynamic attending to test with a series of pitch comparison experiments. The hypothesis at the time was that because neural oscillations are activated by “metric rhythmic events” and “extrapolate an induced beat”, participants would perform better at judging the pitch of a tone when it arrived at the precise metric position after listening to a sequence of interpolating tones (Jones, 2002). Specifically, a participant was given a standard tone, comparison tone, and asked to rate the comparison tone as higher, lower or equivalent in pitch after hearing a series of interpolating tones. During the interpolating tones, the rhythm (each note separated by the same amount of rest/silence) was constant, but the rest between the last interpolating tone and comparison tone was varied (known as the critical interonset interval or IOI) to simulate the note arriving late or early. In conducting this study, Jones and colleagues observed statistically significant results that showed participants performed most optimally when the comparison tone arrived exactly (600ms) after the last interpolating tone and worse when the tone arrived early or later. Several similar experiments were repeated (including performance comparison with an irregular context), and all supported this observation – that when the note arrived “on time”, participants performed their best in identifying the pitch of that note.

From a purely sensibleness standpoint, these results make sense: individuals perform best at a task when they expect it to happen. However, recent research conducted have failed to replicate Jones’ initial findings in 2002, casting doubt on the viability of the dynamic attending theory hypothesis. In 2015, Bauer and colleagues replicated the study conducted by Jones and colleagues with the modification of few different technicalities such as removing the standard tone from the series of interpolated tones to prevent participant bias as well as other small modifications designed to boost performance (inclusion of rest period, introduction of a metronome). The results in this study did not support dynamic attending theory, with “only 40 of the 140 tested participants showing the hypothesized pattern of an inverted U-shaped profile ”(Bauer 2015). In other words, most participants performed about the same regardless of the comparison note arriving early, later, or at the precise metric position thereby refuting Jone’s theory altogether.

Further research also showed similar trends in attempting to replicate Jones' original 2002 pitch comparison task study: a refutation of temporal expectancies affecting accuracy. As recent is 2019, researchers were still unable to replicate that participants perform better when notes came at an expected time. Prince and Sopp at Murdoch University even added a drum beat in hopes of “strengthening the metrical framework” so that a temporal expectancy profile could be better observed, but that experiment too failed to produce statistically significant results in pitch comparison (Prince and Sopp, 2019). However, Prince and Sopp did observe increased accuracy in identifying the length of a note (in relation to a standard note) in one of their experiments, which does support dynamic attending theory: instead of asking participants to compare the pitch of notes, they were asked to compare the relative length of the note. This successful replication, while technically different, shows the vitality of dynamic attending theory.

The first goal of this research project will be to attempt to replicate Jones’ original pitch comparison study, as others have done. A/B Testing will be done to test the hypothesis that timing of the comparison tone and rhythm of interpolating notes will affect participant performance in identifying the pitch of the note. In case of successful replication of Jones’ findings, we can be sure of dynamic attending theory and that when participants perceive regularly rhythms, they are able to perform better in tasks, supporting the conclusion that neural oscillations are present in the formation of our attention spans.

Researched have also postulated a variety of reasons for their failure to replicate expected findings with one likely explanation being that participants failed to recognize the rhythm or temporal expectancy after listening to the interpolated tones. As such, the second goal of this paper is to look deeper into how the underlying oscillations are created and alter throughout course of a participant’s attention span with a series of additional questions exploring the thought process of each subject when completing the pitch comparison task.

Based on past theory and research, evidence of dynamic attending theory should be present, but neural oscillations may be either attenuated or exemplified by a person’s external stimuli such as a drum beat, attention level, or other factors. Each participant may have different formation of oscillatory peaks for the same stimulus, and those who recognize the underlying rhythm and establish a temporal expectancy will perform better when the comparison tone arrives at the precise metric position.

**Experiment 1: Replication of Jones et al. study**

**Materials & Method**

Basing off of Jones’ original 2002 study, a single standard tone, eight interpolated tones, and a final comparison tone arriving either very early, early, on-time, late, or very late, were played to 30 participants. I observe the performance at each time sequence. The almost exact note sequence was used, with only the standard tone and comparison tone being modified at each sequence (early, late, etc.) to prevent participant bias. In all cases, the comparison note was only a half-step higher than the standard note, the smallest possible difference selected in order to make the pitch comparison task as difficult as possible (for sequences see Figure 4). However, a modification to the task was that participants were also given a control sequence, where they were told to respond to a two-note sequence, indicating if the second note was higher or lower than the first note. Because up to 5% of the population having amusia, the aim for this additional sequence was to identify participants that may have amusia, which may prevent skew of results (Harvard Health 2007). Like the original study, an isochronous pattern was formed using eighth rests between each interpolated tone, with a varying number of rests between the final interpolated tone and the comparison tone to simulate early, late, etc (Figure 4).

To standardize the experiment as much as possible, participants were invited to listen to a series of six unique sequences played by audio generated by Noteflight, an online music notation software. Given the limitations of COVID-19 and that participants were spread out over several time zones, the experiment was conducted asynchronous through a Google Form survey (link to full survey in GitHub Repository under Author’s Note), with precise instructions such as only listening to each sequence once in order to minimize bias to the extent possible.

Additional demographical data such as whether or not the participant had perfect pitch, number of years of musical training, and age was also collected (allowing for any follow-up data analysis as needed. Data was fully anonymized to protect participant privacy.

Under the assumption of DAT, and that an individual’s neural oscillations of attention can be unconsciously derived from rhythmicity, participants should perform better when the comparison tone arrives at the precise metric position as they should have undergone entrainment from the series of interpolating tones (Jones 2002). An A/B hypothesis test of 1000 trials would be performed across all distributions (general distribution vs precise metric position, precise metric position vs very early, etc.) and a p-value of <= 0.05 will confirm this hypothesis.

**Results & Discussion**

I did not see the inverted U pattern that Jones saw in her original study where she showed that optimal performance appeared when the note arrived at the precise metric position. When the comparison tone arrived very early, participants correctly identified the pitch 56% of the time, 81% of the time when early, 67% of the time when at the precise metric position, 33% of the time when late, and 54% of the time when very late (Figure 1). In addition, when played a sequence that had an irregular rhythm, participants correctly identified the pitch 33% of the time. Upon performing hypothesis testing I saw that when comparing the distributions of late to on-time, the results were statistically significant (P= 0.0), that is, participants performed clearly worse when the comparison tone arrived late. However (and rather unexpectedly), participants also performed better when the comparison tone arrived early (but not very early) when comparing to when the tone arrived on time (p = 0.03). Nevertheless, when compared to the overall distribution, participants still performed better on average when the tone arrived at the precise metric position (p = 0.05).

These results, while different from the ones seen done by Jones, were in line with the results seen by Prince et al. and Bauer et al. where an inverted U-shaped distribution (such that performance is optimal at the precise metric position) supporting DAT were not seen. Possible explanations for failing to replicate the expected results could be that the sample size was too small, or that when administering the experiment, users were not prepared or did not hear the tones well. Jones and colleagues had prepared their participants by doing practice sessions, but given the limitations of this experiment, conducting live practice sessions was not feasible. Another possible explanation was that perhaps the underlying sinusoidal periodicity was not yet well formed when the comparison tone arrived, with external stimuli such as temperature and light playing a role in how an individual perceives music (Huron, 2006). Jones and colleagues performed the experiment in a quiet, light-controlled room, a stipulation that was not always possible in this study.

While these results do not directly support DAT, there are some interesting observations that suggest that DAT is still a valid hypothesis. Specifically, the observation that participants performed worse when the pattern was irregular and much better when the note arrived at the expected timing suggests that rhythm, and by extension neural oscillations, do have an effect on how individual’s attention changes in relation to a wave.

**Experiment 2: Further investigating individual elements from Jones et al. study**

**Materials and Method**

Given that results were mixed in Experiment 1, I decided to conduct another experiment that attempts to investigate more deeply if neural oscillations were formed, and how they affect a participant’s attention. One possible explanation for the failure to replicate results in Experiment 1 were that the oscillations may not have been well formed. Periodic rhythms can be enhanced with a drum beat or metronome, so a metronome tone of 130 playing softly in the background was added (Prince and Sopp 2019). A brief rest was also added between the standard tone and interpolating distractor tones, allowing a participant to better encode the standard tone into memory (Figure 5). In this experiment, only sequences of very early, on time, very late, and irregular were played in order to shorten the study as some participants from experiment 1 indicated that the study was too long. With these modifications, I believed that participants would perform better given that temporal expectancies are strengthened. A/B hypothesis testing was again performed to see if the performance of each distribution were significantly different from each other.

Additional data was also collected to determine if a participant noticed anything about the timing of the final, comparison note. The reasons were that if participants did not notice the different inter-onset intervals (IOI), their performance may be less influenced on the timing of the comparison tone as subsequent A/B hypothesis testing will eventually confirm. Participants were also asked to determine which sequence (very early, on-time, very late, or irregular) was easiest.

Lastly, principal component analysis (PCA) using the first principal component was done as a way to explore any future work that could be done and to see if any specific data was correlated.

**Results & Discussion**

The results in this experiment supported DAT, where an inverted U shape performance distribution was seen (Figure 2). Participants performed best when the comparison tone arrived at the normal metric position (87%), followed by arriving very late (85%), followed by very early (70%), and lastly when there was no rhythm (64%). This result was statistically significant when comparing the distribution of very early to normal metric position (p = 0.004) and also when comparing the distribution of irregular to normal metric position (p = 0.0). While the results were not statistically significant when comparing the distribution of very late to normal (p = 0.23), they nonetheless suggest a trend supporting DAT.

Upon further inspection, participants who correctly identified the timing of the comparison tone (i.e., they noticed if the tone arrived later or earlier than expected), performed better at determining the pitch of the comparison tone than participants who did not correctly identifying the time of the comparison tone (p < 0.05). The basis of DAT is that there “is a concentration of attentional energy with each cycle of the oscillation…modeled as a periodic probability density function” (Henry and Herrmann ,2013). As such, an explanation for why participants performed better when they correctly identified the timing could have been that those who did not realize that the comparison tone arrived early/late/on time had malformed probability density functions and that their oscillatory peaks were not well formed. Also supporting DAT was that the majority of participants(~58%) identified the sequence that had a normal interonset interval (comparison tone arrive on time) easiest followed by very late (Figure 3). This shows that even if participants did not correctly identify the comparison tone’s pitch, neural oscillations of some sort likely had formed, and that attention was optimal when the tone corresponding to the sinusoidal peak.

Finally, PCA analysis did not provide much insight for this experiment. However, correlations were detected among correctness of sequences (if I identify one note’s pitch correct, I am likely to identify another note correct).

**General Discussion & Conclusion**

Most notable during this replication study was that despite both experiments being similar, different results ensured. However, this was not unusual as past researchers who attempted to replicate the findings from Jones et al (2002) also received mixed results. Namely, temporal expectancies were not found to affect accuracy in determining pitch, loudness, or timbre, but only duration in one study (Prince and Sopp 2019) and that participants performed roughly the same irrespective to when a comparison tone arrived (Bauer et al. 2015). All of this highlights how difficult it is to investigate the underlyings of dynamic attending theory.

Past research has shown that neural oscillations are both self-sustaining, has an intrinsic frequency, and can be modified with external stimuli with the possibility of multiple oscillations/waves being possible at one time (Henry and Herrmann 2013, Oxford Handbook of Musical Psychology). These assumptions could have explained why participants performed significant better when a metronome was introduced, such that even if participants did not recognize the rhythm with the interpolating tone, the beat of the metronome helped created a singular sinusoidal wave that aligned peaks to when the comparison tone arrived on time. Unknown external stimuli from a participant’s testing environment in the first experiment could have modified the oscillatory peaks, which explained the relatively poor performance and mixed results. By keeping a participant “on track” with a metronome and giving them more time to encode the standard tone with a brief rest period, their attention peaks were better formed, and clear evidence of DAT was seen.

Furthermore, even in participants who did not perform well in these pitch comparison tasks, they still responded overwhelmingly that Sequence 1 in Experiment 2, the sequence that had the final note arrive at the normal metric position, was the easiest sequence to identify the correct pitch. Much of our auditory processing can be unconscious (Huron, 2006) and it appears that even when participants incorrectly identified timing and pitch, there was an underlying preference towards Sequence 1.

In conclusion, while initial results were mixed, both experiments show clear evidence for dynamic attending theory. In addition, the studies conducted here also show that our neural oscillations can be exemplified with the help of external stimuli and may be different for everyone depending on a person’s environment. But in the end, these oscillations exist and are often unconscious to an individual’s perception but evident through empirical evidence. As such, future work could expand onto how these oscillations affect a participant’s judgement, and if DAT can extend beyond simple pitch comparison or a musical context.

Bibliography

Bauer, A.-K. R., Jaeger, M., Thorne, J. D., Bendixen, A., & Debener, S. (2015, April 28). *The auditory dynamic attending theory revisited: A closer look at the pitch comparison task*. Brain Research. https://www.sciencedirect.com/science/article/pii/S0006899315003285.

Henry, M. J., & Herrmann, B. (2014). Low-Frequency Neural Oscillations Support Dynamic Attending in Temporal Context. *Timing & Time Perception,* *2*(1), 62-86. doi:10.1163/22134468-00002011

Huron, D. (2008). *Sweet anticipation: music and the psychology of expectation*. MIT.

Jones, M. R., Moynihan, H., Mackenzie, N., & Puente, J. (2002). Temporal Aspects of Stimulus-Driven Attending in Dynamic Arrays. *Psychological Science*, *13*(4), 313–319. https://doi.org/10.1111/1467-9280.00458

Oxford University Press. *Oxford Handbook of Music Psychology*.

Prince, J. B., & Sopp, M. (2019). Temporal expectancies affect accuracy in standard-comparison judgments of duration, but neither pitch height, nor timbre, nor loudness. *Journal of Experimental Psychology: Human Perception and Performance*, *45*(5), 585–600. https://doi.org/10.1037/xhp0000629

Publishing, H. H. (2007). *Tone deaf test*. Harvard Health. https://www.health.harvard.edu/press\_releases/tone-deaf-test.

Appendix

Chart, bar chart

Description automatically generated

**Figure 1**: Graph of % of participants correctly identifying the pitch in Experiment 1.

Chart, bar chart

Description automatically generated

**Figure 2:** Graph of % of participants correctly identifying the pitch in Experiment 2.

Chart, bar chart

Description automatically generated

**Figure 3**: Graph of % of participants responding to which sequence was easiest in Experiment 2.

A picture containing graphical user interface

Description automatically generated

**Figure 4:** Sequence from Experiment 1

A picture containing graphical user interface

Description automatically generated

**Figure 5**: Sequence from Experiment 2