

Transcranial Magnetic Stimulation Investigation of the Frontoparietal Attention Network

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LIST OF ABBREVIATIONS

A1.....	Primary Auditory Area
BOLD.....	Blood Oxygen Level-Dependent
DAT.....	Dynamic Attending Theory
EEG.....	Electroencephalography
FEF.....	Frontal Eye Field
fMRI.....	functional Magnetic Resonance Imaging
FPAN.....	Frontoparietal Attention Network
IOI.....	Inter-Onset Interval
IPC.....	Inferior Parietal Cortex
IPL.....	Inferior Parietal Lobule
IPS.....	Intraparietal Sulcus
M1.....	Primary Motor Area
PMC.....	Premotor Cortex
raTPJ.....	right anterior Temporoparietal Junction
rVIPS.....	right Ventral Intraparietal Sulcus
S1.....	Primary Somatosensory Area
STG.....	Superior Temporal Gyrus
tACS.....	transcranial Alternating Current Stimulation
TBS.....	Theta-Burst Stimulation
TMS.....	Transcranial Magnetic Stimulation
TPJ.....	Temporoparietal Junction
V1.....	Primary Visual Area

ABSTRACT

TRANSCRANIAL MAGNETIC STIMULATION INVESTIGATION OF THE FRONTO Parietal ATTENTION NETWORK

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Dynamic Attending Theory (DAT) suggests that, due to its exorbitant energy requirements, attention regularly oscillates such that an individual experiences high and low energetic states during sustained attending that lead to high and low mental presences, respectively. Attention research is largely focused on endogenous temporal orienting, however, so little is known about the neural mechanisms underlying exogenous orienting as specified by DAT. We used TBS to inhibit the right ventral intraparietal sulcus and right anterior temporoparietal junction during a dynamic attending task to directly observe their roles in attentional entrainment. We found a significant effect of Foreperiod, but likely due to low sample size, we found no significance of IOI, the interaction between the two, or stimulation site. These findings warrant additional research, to determine how inhibition compares to a control site and to increase power in the hopes of replicating the results of Sanabria, Capizzi, and Correa (2011).

LITERATURE REVIEW

Attention is one of our most widely-used resources yet is astoundingly finite. At times, one can appear to focus on multiple tasks simultaneously, often referred to as multitasking, but research has shown that this division is ultimately unsustainable and generally results in the focusing on a single main task (Jefferies & Witt, 2018). These findings might suggest that, while attention cannot be split, perhaps it can exhibit durability across time. Unfortunately, research into the correlation between detection performance on attended versus unattended stimuli has suggested that sustained attention, or the long-term allocation of resources, cannot be maintained at a constant level for long and must instead regularly fluctuate between high and low mental presence (Busch & VanRullen, 2010). This idea, formalized as Dynamic Attending Theory (DAT), was first developed in the late 1970's by Mari Jones, who later suggested that this oscillatory tendency could be entrained through the introduction of isochronous beats and could therefore stretch and shift based on the statistics of the environment (Jones, 1976; Jones, Boltz, & Kidd, 1982; Jones & Boltz, 1989).

Attention

Survival necessitates the flexibility of attention, regularly shifting between what we choose and what we need to focus on. In space, these are referred to as exogenous and endogenous orienting, where the former refers to an involuntary focus on a stimulus

driven by an inherently transient or salient cue and the latter a voluntary and intentional focus to a specific location (Coull & Nobre, 2008). Temporally, however, such concrete definitions were unavailable until those proposed by Coull and Nobre (2008), who suggested that endogenous orienting should refer to the presence of informative symbolic cues to direct attention at a specific moment in time, whereas exogenous orienting should refer to the automatic focus on stimuli with rhythmic or predictable temporal structure (Coull & Nobre, 2008). The combination of these systems allows one to flexibly shift their attention until such time that a specific stimulus or set of stimuli require full awareness, allowing one to preemptively or reflexively react to potentially dangerous situations.

Due to the energy restrictions placed on attention, however, a number of functions have developed that allow us to process our surroundings as if constantly operating at peak arousal. These functions can be divided into two timing categories: periodic and aperiodic. The latter addresses instances in which one is presented with random input offered with little to no warning, such as a yellow traffic light indicating the impending switch to red. This is an example of a symbolic cue, or a memory-based prediction upon which we are always building so as to keep our future predictions as accurate as possible (Rimmele, Morillon, Poeppel, & Arnal, 2018). It also provides us with an indication as to when our attention should peak, and alternatively, when it can remain at its nadir. Hazard functions similarly provide us with aperiodic indicators, but in a less precise way, in that they are based on the probability of an event occurring given that it has not yet occurred (Rimmele et al., 2018). This could be a caesura in a conversation or musical piece, the

start of which inherently hints at the end and is an excellent way to build suspense by maintaining one's attention for longer than is typical. Many times, however, an aperiodic prediction is littered with periodic predictors. Some examples of this include the temporal regularity of speech and music (Calderone, Lakatos, Butler, & Castellanos, 2014), the rhythm created by autonomic bodily functions such as heartrate and breathing (Iwanaga, 1995), or even the presence of actual timers in our environment (e.g. pedestrian crossing signals). These largely isochronous stimuli allow for the tracking of ourselves through time, which in turn allows us to anticipate the appearance of important stimuli (Rimmele et al., 2018). It is important, however, to delineate attention and expectation, as the two are complementary but decidedly unique processes.

Most researchers semantically understand the difference between the two, but there is a severe lack of computational and empirical work exploring the mechanisms of expectation, much of which has been designed around vision (Summerfield & Egner, 2009). Shortly after this claim was purported, researchers in Hungary and the UK sought to address the shortage by disentangling the two experimentally. Their aim was to determine the precise neural mechanisms implicated in decreased reaction times to predictable stimuli using EEG, finding a significant entrainment to tone onset with higher levels of predictability as phase synchronization increased (Stefanics et al., 2010). This was corroborated by Rohenkohl and colleagues (2012), who found that enhanced temporal expectations often modulated perceptual processing by increasing the contrast sensitivity of the visual targets occurring at regular intervals, resulting in improved reaction times and greater identification accuracy. Together, these results suggest that

expectation is a function of attention, in which the latter is highly focused toward a point in time to create the former, but there seems to be a clear mechanistic difference between the two.

Dynamic Attending Theory

Dynamic Attending Theory asserts that attention can entrain to a beat or isochronous rhythm, the placement of which would determine the mental resources available for an individual. Attentional peaks (and the corresponding increased awareness) would then fall along individual beats as well as increasingly towards the downbeat of the measure, while attentional troughs would fall between the beats and increasingly towards the middle of a measure (Jones, 1976). See Figure 1 of the Appendix for a visual representation.

As attention is multifaceted, researchers are still exploring its nuances, leading to inevitable contradictions in the field. For example, recent work conducted by Kunert and Jongman (2017), which tested participants on a lexical-decision task in which they decided whether a string of letters was a word, seemed to show that DAT-predicted effects only extend to auditory-motor synchronization rather than selective attention as a whole. Similarly, results of another study suggest that pitch comparison tasks utilized in more recent research conducted by the original Jones and colleagues (2002) was inadequate and did not appropriately demonstrate auditory dynamic attending, instead proposing that their results could not be generalized (Bauer, Jaeger, Thorne, Bendixen, & Debener, 2015). Fortunately, they suggest that future paradigms should direct attention

solely to a specific moment in time without confounding it with additional requirements, such as making pitch judgements.

In 2011, Sanabria and colleagues used a modified version of the temporal orienting paradigm to test whether attention could be directed to different moments in time by different tempos to decrease reaction times. As expected, results demonstrated an improved reaction time in both short and long intervals, implicating a highly flexible mechanism behind dynamic attending (Sanabria, Capizzi, & Correa, 2011). Additional research has found that dynamic attending can improve not just reaction times and motor processing (Kunert & Jongman, 2017), but perceptual processing as well (Correa, Lupiáñez, & Tudela, 2005; Rohenkohl et al., 2012). This is further substantiated by electrophysiological research on the topic, and suggests an improvement in signal-to-noise ratio during peaks of dynamic attending (Correa & Nobre, 2008; Jones, Hsu, Granjon, & Waszak, 2017; Schroeder & Lakatos, 2009; Stefanics et al., 2010).

Physiological Research

Given that DAT can be entrained along a rhythm to effectively modulate behavior, focus has shifted from “do we do it?” to “how does it work?”. It is well-understood that the basal ganglia and supplementary motor area are highly involved in entrainment to and reproduction of a regular beat (Bengtsson et al., 2009; Grahn & Brett, 2007; Grahn & Rowe, 2009; Meck & Benson, 2002), but frustratingly little has been observed in DAT-specific networks and their immediately-related regions. Todd and colleagues (2002) proposed a neural network primarily involved in temporal tracking and beat induction that doesn't explicitly mention the basal ganglia, likely due to its role in numerous other

systems that would result in the information exiting the dynamic attending stream. This network originates in what they refer to as the plant (the body), the internal operations of which lay the groundwork for sensory comparisons, which is then followed by a sensory processing loop that involves the primary auditory area (A1), the superior temporal gyrus (which they refer to as “a kind of ‘auditory v5’”), and the inferior parietal lobule (IPL). As expected, the A1 processes auditory input and computes a spatio-temporal power spectrum. The “A5” then interprets this information in terms of melodic (right STG) and phonetic (left STG) motion. Both areas feed into a feedback loop with the IPL, which gathers information, compresses it into audio-motor intentions and attentional sets, and forwards it to a planning and control feedback loop between the IPL, premotor cortex (PMC), and lateral cerebellum. In the final step, the PMC translates the auditory coordinates provided by the IPL into motor coordinates and sends this information to an execution loop between the primary motor area (M1), primary somatosensory area (S1), and intermediate cerebellum. The M1 sends motor commands to the plant, which can either provide auditory feedback to the ear (effectively restarting this process) or somatosensory feedback to S1. S1 can similarly provide somatosensory feedback to the IPL (Todd, Lee, & O’Boyle, 2002). As this network deals primarily with auditory entrainment, a similar network likely deals with visual entrainment to a beat, which is corroborated by Lakatos and colleagues (2008).

In 2008, Lakatos and colleagues wanted to see how the allocation of attention to a rhythmic stream altered sensory cortical oscillatory tendencies and the resulting neuronal response amplitude and reaction times. They tested monkeys on an intermodal selective-

attention task that employed both visual and auditory stimuli to entrain their attention while using a linear multielectrode array to record laminar profiles of field potentials and concomitant multiunit activity in the primary visual cortex (V1). While only 2 macaques participated in 24 experimental sessions each, results showed that delta-band oscillations of the V1 entrained to the presented rhythmic stream, and thus that visual sensory areas can effectively entrain to a beat (Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008).

Additionally, research with transcranial alternating current stimulation (tACS) observed how the introduction of specific oscillations can alter and entrain participants along certain dynamic attending-related tasks. Helfrich and colleagues aimed to further quantify the entrainment of alpha oscillations, so they applied 10 Hz tACS to the parieto-occipital cortex while participants underwent simultaneous EEG in a novel approach that the authors claim could separate stimulation artifacts from the appropriate cortical activity. Their results demonstrated that this entrainment increased parieto-occipital alpha activity and adequately synchronized cortical oscillators to their introduced frequency, as well as improved target detection (Helfrich et al., 2014). This suggests that, not only are alpha oscillations highly involved in visual perception, but parieto-occipital areas are likely involved with inhibiting the processing of irrelevant sensory inputs and the resulting improved memory performance. Similar results by researchers Hopfinger, Parsons, and Frohlich (2017) found that gamma stimulation to the right inferior parietal cortex resulted in improved attentional disengagement (specifically from invalidly-cued targets), which is maintained by previous research (Hilgetag, Theoret, & Pascual-Leone,

2001; Chambers, Payne, Stokes, & Mattingley, 2004; Thut, Nietzel, Brandt, & Pascual-Leone, 2006; Rihs, Michel, & Thut, 2009).

Finally, studies employing functional magnetic resonance imaging (fMRI), such as work conducted by Coull, Cotti, and Vidal (2016) have provided invaluable insight into the discussion. In this study, the researchers aimed to identify the specific regions involved in fixed versus evolving temporal predictability, and found that fixed cues were more likely to activate the left inferior parietal cortex (IPC), while tracking hazard functions involved the left and right IPC, resulting in an improvement in reaction times following longer foreperiods (Coull et al., 2016). The identification of an attention-related network of connections in the fronto-parietal pathway further confirms the likelihood of IPC involvement in temporal prediction.

Fronto-Parietal Attention Network

Researchers have long understood the connection between attention and the fronto-parietal attention network (FPAN), even if only indirectly, as studies conducted in the 1980's observing patients with unilateral neglect to the right parietal lobe found significant attentional impairments (Heilman & Van Den Abell, 1980; Hopfinger et al., 2017). In 2000, Hopfinger, Buonocore, and Mangun utilized fMRI during a cued spatial-attention task to differentiate between brain activity present for stimulus processing compared to attentional control. They found that the superior frontal, inferior parietal, and superior temporal cortices were activated by cues (Hopfinger, Buonocore, & Mangun, 2000), implicating their individual roles in endogenous attending. Further results found that temporary disruption of the parietal cortex leads to reduced stimulus

detection in the contralateral visual field, but increased in the ipsilateral (Hilgetag, et al., 2001). This finding not only demonstrates the plasticity regarding unilateral damage, but also implies that future research should keep this phenomenon in mind when designing attention-measuring tasks that involve any form of unilateral stimulation.

As stated above, attention can be divided into two categories, endogenous (top-down or goal-driven) and exogenous (bottom-up or stimulus-driven). It would then be appropriate to suggest that the structural pathways of the FPAN were similarly divided. Consistently, attentional control appears to operate through two cooperative streams (Corbetta & Schulman, 2002). The endogenous network traverses the primarily bilateral intraparietal sulcus (IPS) to frontal eye field (FEF), which assist in the genesis of attentional sets and their application during stimulus processing, while the second interaction seems to be lateralized to the right hemisphere of the temporo-parietal junction (TPJ; the intersection of the inferior parietal lobule and superior temporal gyrus) to the IPS, and operates primarily as an alerting mechanism for the first system. It is important to note, however, that the endogenous network seems to be similarly modulated by stimulus-driven control (Chica, Bartolomeo, & Valero-Cabré, 2011; Corbetta & Shulman, 2002; Markett et al., 2014). Alternatively, Kincade et al. (2005) found no activation of the ventral network during orientation, implying the presence of only a single dorsal frontoparietal network to control both endogenous and exogenous attending, but is outnumbered by research that states otherwise (Chica et al., 2011). These data suggest that the IPS and TPJ are crucial junctions between the two streams, yet their role in dynamic entrainment remains unknown.

Further exploring the TPJ, research has shown that it is implicated in 3 subsystems: a dorsal cluster that interacts primarily with lateral anterior prefrontal cortex (among others); a ventral cluster that interacts with ventral prefrontal cortex; and a posterior cluster that interacts with posterior cingulate, temporal pole, and anterior medial prefrontal cortex (Mars et al., 2012). According to Wang, Tarn, and Smith, who looked at functional connectivity by parceling different regions based on brain-wide patterns of coactivations, all clusters in the left TPJ were predicted primarily by memory, social, decision-making, and awareness; the ventral cluster, however, was more heavily activated by tasks involving reading, semantics, and emotion, while the anterior cluster was more highly activated by priming (Wang, Taren, & Smith, 2018). Finally, research conducted by Shulman and colleagues observing the role of the rTPJ in the filtering of behaviorally irrelevant information by analyzing changes in blood oxygenation level-dependent (BOLD) response shows increased deactivation pre-stimulus and increased activation post-stimulus, further implying its role in attentional processes (Shulman, Astafiev, McAvoy, d'Avossa, & Corbetta, 2007).

This project intends to directly study the role of the right ventral intraparietal sulcus and right anterior temporoparietal junction in modulatory rhythmic sampling and the effects of a dynamic attending task on these processes through transcranial magnetic stimulation (TMS). There will be three experimental manipulations: the area stimulated (the right ventral intraparietal sulcus or the right anterior temporoparietal junction), foreperiod length (200, 400, 900, 1400, or 1600 ms), and stimulus inter-onset interval (450 or 950 ms). Offline TMS will be administered before participants complete a visual

discrimination task that includes an isochronous rhythm along which attention can entrain.

METHOD

Participants. 5 healthy students (4 females, mean age = 29.2) from George Mason University were recruited and randomized to receive TBS at either the raTPJ or rVIPS during their first session. Participants were right-handed, physically healthy adults who did not demonstrate any previous history of head injury, seizures, migraine, neurological or psychological disorders, alcohol or drug abuse, and could not be pregnant, nursing, or possibly pregnant.

Design. We used a 2x5x2 within-subjects design with stimulation site, foreperiod length, and inter-onset interval (IOI) as independent variables. Stimulation site had 2 levels: the right ventral intraparietal sulcus and the right anterior temporoparietal junction. Foreperiod length had 5 levels: stimulus presentation occurred after a foreperiod of 200, 400, 900, 1400, or 1600 ms. Finally, inter-onset interval had two levels: either 450 or 950 ms.

Materials. We used a task similar to that of Sanabria, Capizzi, and Correa (2011) (see Figure 2 of the Appendix). Stimuli were presented on a Gaming LED Dell monitor running at 100Hz refresh rate using E-Prime 2.0, with volume adjusted to each participant's personal preference on external speakers. Participants were asked to perform a go/no-go task in which they pressed a key to indicate if an image appeared and refrain from pressing a key if it did not. For the purpose of this study, a CHERRY MX Red

STRAFE Mechanical Gaming Keyboard was used as it allows for more accurate reaction times to be recorded (1000Hz polling rate).

Prior to starting the task, participants underwent offline transcranial magnetic stimulation (TMS) to one of our stimulation sites. During the task, a steady rhythm was present in the background to initially entrain attention.

Procedure. Two iterations of the task were completed on separate days, and stimulation order (rVIPS, raTPJ) was randomized between participants.

Participants were seated in front of a computer before completing an informed consent form. Once the form was collected, the participant completed a short series of practice trials before the researcher located and stimulated either the rVIPS (MNI coordinates: 35, -85, 27; Markett, S., et al., 2014) or the raTPJ (MNI coordinates: 58, -37, 20; Mars, R. B., et al., 2012) using theta-burst stimulation (Huang, Y.-Z., et al. 2005). Each participant had previously acquired a high-resolution, T1-weighted MRI structural scan that was uploaded to Brainsight (Rogue Research), a 3D frameless stereotactic system for localizing the stimulation site for each participant. Additionally, participants were stimulated by a Magstim Rapid2+ TMS system using a figure-of-eight air-cooled coil set at 40% of stimulator output. Once stimulation was completed, the participant began the first iteration of the task.

Participants received written and verbal instructions to respond to the appearance of the image as quickly as possible by pressing the space bar with their dominant index finger. They were informed that the tempo of the rhythm indicates the probability of target appearance (i.e. the faster rhythm indicates that there is a higher likelihood the

image will appear early and vice versa). Additionally, they were told that the last tone in the rhythm, which was higher in pitch than the preceding 5, marked the start of the foreperiod.

A trial began with the presentation of a fixation cross, which remained onscreen until the end of the session. Five hundred milliseconds after the trial began, the appropriately speeded auditory sequence was presented. The sixth tone in the auditory sequence marked the beginning of the foreperiod and the consequential preparation for image presentation. As stated, the image was presented after a foreperiod of either 200, 400, 900, 1400, or 1600 ms. A maximum duration of 2000 ms was allowed to respond to image presentation before the next trial began. Based on the results of Sanabria and colleagues (2011), catch trials, during which no stimulus image was presented and participants were instructed to not respond, were implemented to ensure attention to the task. There were 4 blocks of 60 trials each (20 of which were catch trials), with an untimed break between blocks. See Figure 2 for a representation of the task.

After completing of the first iteration of the task, participants were scheduled for their second meeting. Upon arrival on the second day, participants completed the practice trials once more before being stimulated at the final site and asked to complete the full task a second time. Due to the findings by Huang and colleagues, which suggest that theta-burst stimulation effects typically only last up to approximately 40 minutes (2005), a single iteration of the task took approximately 32 minutes to complete.

RESULTS

Median reaction time was calculated for each participant and analyzed using a repeated-measures ANOVA with the factors of Stimulation Site, Foreperiod, and Inter-Onset Interval. Median data were used to avoid unwarranted effects due to outliers and the non-normal distribution of reaction times, as suggested by Ratcliff (1993). Data from the practice block were not included in the analysis.

Similar to the results of Sanabria, Capizzi, and Correa (2011), we found a significant main effect of FP, $F(4,16) = 13.85$, $p < .001$, $\eta^2_p = .776$ and no significant main effect of IOI, $F(1,4) = 1.85$, $p = .245$. Dissimilar to previous researchers, however, we did not see an interaction effect of Foreperiod x IOI, $F(4,16) = .97$, $p = .195$. Finally, there was no significant main effect of Site, $F(1,4) = .013$, $p = .92$, or interaction effects of Site x FP, $F(4,16) = 1.17$, $p = .226$, Site x IOI, $F(1,4) = .00$, $p = .98$, or Site x FP x IOI, $F(4,16) = 1.48$, $p = .269$. Please see Figure 3 of the Appendix for reaction time data.

DISCUSSION

The present study tested two primary hypotheses. The first was that individuals who receive stimulation to the right ventral intraparietal sulcus will demonstrate overall slower reaction times than to the right anterior temporoparietal junction. The second, as an individual's foreperiod length more closely matches their inter-onset interval, reaction times will improve.

Unfortunately, our results did not reach significance for any main or interaction effects besides foreperiod. This suggests that, according to our data, attention was not exogenously oriented differently between inhibition of the right anterior temporoparietal junction and right ventral intraparietal sulcus, suggesting that the two either don't alter dynamic entrainment or they affect it in the same way; a third control site would be necessary in future studies to determine which is the case. Additionally, our findings, which partially support those of Sanabria, Capizzi, and Correa (2011), suggest that reaction times following isochronous beat entrainment are adjusted by foreperiod length, but not in the way that we had anticipated. Sanabria and colleagues included catch trials in an attempt to reverse the inherent hazard effect of a foreperiod task, however our data show no similar reversal (Figure 3). Interestingly, our data more closely replicate those of Experiment 2, before catch trials were implemented, rather than Experiment 3 like we had anticipated; while we replicated the classical foreperiod effect, we found no orienting effect of IOI, which cannot be explained by uncertainty. Due to lack of a control

condition without rhythmic stimuli, we cannot assert that these reaction times were faster than if we had presented the stimuli without a beat entirely, but previous research suggests this is the case (Jones, 1976; Correa and Nobre, 2008; Rohenkohl et al., 2012; and Kunert and Jongman, 2017).

The lack of replication in terms of Sanabria and colleagues' (2011) Experiment 3 is curious as it suggests that one of two scenarios likely occurred. It is possible that there was no effect of stimulation on either of our sites, suggesting that our lack of foreperiod reversal was due to either low power or too few catch trials and that increasing the ratio from 1/3 to 1/2 and recruiting significantly more participants would lead to the reversal we originally anticipated. Alternatively, given that information from both sites flow through the same junction of the FPAN, stimulation could have removed the effects of catch trials entirely, suggesting that either one or both areas are directly involved in the utilization or inhibition of the hazard function in dynamic entrainment. Should this be the case, future studies should focus on replacing one of the original stimulation sites (given its placement, we recommend the rVIPS) with one of another stream of the FPAN (such as the FEF).

In terms of Dynamic Attending Theory, our results have demonstrated that rhythmic-induced temporal orienting is overall a flexible mechanism, otherwise we would have seen a significant difference for IOI, which was not the case. In other words, faster rhythms can effectively focus attention earlier in time while slower rhythms can focus later; this is important in terms of all rhythmic entrainment, not just auditory. As stated by Sanabria and colleagues (2011), we acknowledge that the results may be

confined by the rhythmic speed, of which we only presented two. We postulate, however, that the results would be generalizable upon increased power to additional rhythmic paradigms.

One major limitation of this study is power, as TMS studies such as this are limited to participants who have undergone MRI and those who are willing to return for a second session. In our case, there were also a number of unforeseen circumstances that drastically limited the number of participants to be collected before the thesis deadline, which likely significantly affected our data. Provided more time, we would have ideally collected approximately 20-25 individuals, 15-20 more than the current situation allowed.

Another possible limitation is the stimulation site. It is possible that, behaviorally, both the right ventral intraparietal sulcus and right anterior temporoparietal junction are equally involved in exogenous orienting (as the rVIPS seems to exist in both the ventral and dorsal stream of the FPAN and precedes the raTPJ) suggesting that inhibition of one inherently results in at least mild inhibition of the other. Future studies should focus on empirically differentiating the two, either by introducing a third control site or replacing one of the original sites with one in an alternate stream.

In sum, our study introduced a novel design to further observe and quantify the effects of dynamic attending and attentional entrainment by isochronous auditory rhythms but likely due to low power saw few significant results, only replicating some of previous researchers' findings.

APPENDIX 1

DAT – Attentional Energy Over Time

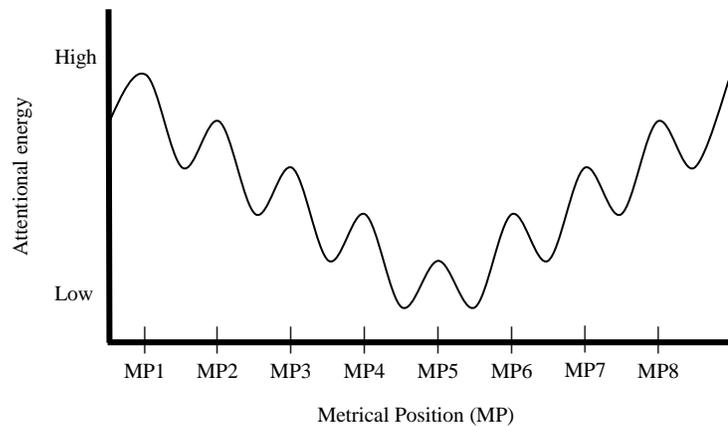


Figure 1. Representation of DAT – Attentional peaks (and the corresponding increased awareness) would fall along individual beats as well as increasingly towards the downbeat of the measure, while attentional troughs would fall between the beats and increasingly towards the middle of a measure (Jones, 1976). Metrical Position refers to the placement of a beat in an 8 count measure, in which each beat occupies the same amount of time as another to create an isochronous rhythm.

APPENDIX 2

The Task

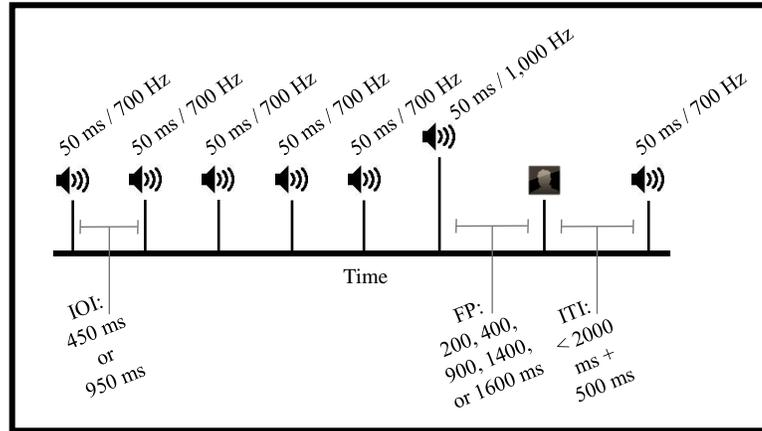


Figure 2. This figure has been adapted from that of Sanabria, Capizzi, and Correa (2011). The task involves 5 notes (700 Hz, 50 ms) (represented by a speaker icon) played consecutively, followed by a warning tone (1,000 Hz, 50 ms). The inter-onset interval (IOI) will be either 450 ms or 950 ms, depending on the condition completed by the participant. Following the warning tone, there will be a foreperiod (FP) of either 200, 400, 900, 1400, or 1600 ms before the presentation of the stimulus (an image, unlike the original task which used an additional note) Findings by Bolger, Trost, and Schon (2013) suggest that cross-modal interactions, such as switching between tones and images, are unlikely to alter results alone. Finally, after the stimulus is presented, the participant will be allowed up to 2,000 ms to respond before the intertrial interval (ITI) of 500 ms, which precedes the start of the next set.

APPENDIX 3

Reaction Time Data

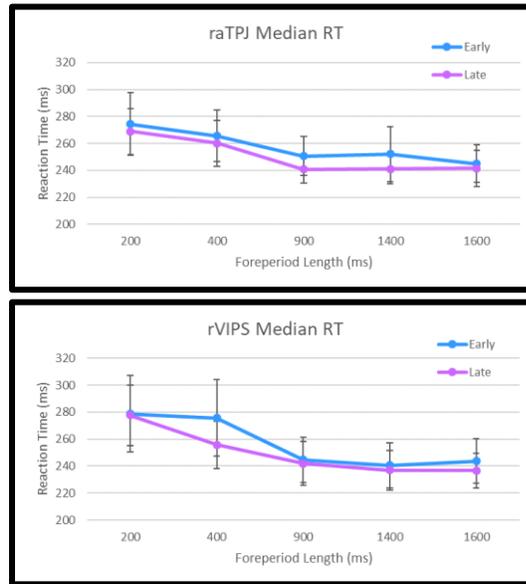


Figure 3. This figure shows the average median reaction time of each participant across each of the 5 Foreperiods (200, 400, 900, 1400, 1600) as they relate to the IOI (Early or Late); error bars are standard error of the mean median reaction time. As previously stated, we did not see a significant main effect of Foreperiod, IOI, or the interaction between the two. Stimulation Site was also not significant. To compensate for the hazard effect seen in our current data and Experiments 1 and 2 of Sanabria, Capizzi, and Correa (2011), catch trials were included in the task; these did not reverse the Foreperiod effect as seen by the original researchers in our current study.

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