Does Modulation in Music Influence Sustained Attention?

Ayla Hadley
Northeastern University
MUST4611
Boston, MA
Hadley.ay@northeastern.edu

ABSTRACT

The objective of this research project is to replicate a pre-existing study under novel and altered conditions. The study being replicated is titled "Modulation in Background Music Influences Sustained Attention," [Woods, Kevin J P, et al. "Modulation in Background Music Influences Sustained Attention." *ArXiv.org*, 16 July 2019, https://arxiv.org/abs/1907.06909] which investigates the impact of amplitude modulation in music on sustained attention. Amplitude modulation is a technique that generates variations in the amplitude of a carrier signal. In this experiment, amplitude modulation at 16 hertz serves as a means to manipulate musical sounds and influence cognitive task performance.

As an individual with a keen interest in meditation and studying with music, an original ambient piece tuned to 432 Hz has been created, which has been scientifically demonstrated to enhance relaxation and focus. The experiment introduces two ambient compositions: one incorporating amplitude modulation and another without it. Both pieces are tested on participants to obtain quantitative data, which is anticipated to correspond with the results of the original study, further advancing our understanding of the relationship between amplitude modulation in music and sustained attention.

1. INTRODUCTION

The main piece of work that inspired my capstone project is the work by Woods et al. who's experiment attempts to answer the questions, how should music be designed to aid performance? and what are the effects of acoustic modulation on sustained attention? In order to understand how certain characteristics of music can help influence sustained attention, the study manipulated the rate and depth of amplitude modulation added to background music. Research shows that music with added modulation(s) synchronize neural activity at higher rates than music normally without any added modulation. [Woods, Kevin J P, et al., 2019]

Sustained attention refers to the ability to hold focus over time and this can often be interrupted by mind-wandering and impulsivity. Background music is specifically used in this experiment because it is commonly used as an aid to promote focus, regulate emotion, and improve mood. [Thompson, Schellenberg & Husain, 2001; Schellenberg & Hallam, 2005; Roth & Smith, 2008; Palmiero et al, 2015; Elvers & Steffens, 2017]. One interest of this study was how modulations in music can be beneficial for those with symptoms of inattention and/or hyperactivity such as Attention Deficit Hyperactivity Disorder (ADHD) and/or Attention Deficit Disorder (ADD). One neurological characteristic of ADHD is that it is associated with decreased beta-band cortical activity. Another interest of this study was the effect of personality, introversion versus extroversion, on the impacted of modulated background music.

Two experiments were conducted, each with six conditions: no-modulation, 8 Hz medium depth modulation, 16 Hz medium-depth, 32 Hz medium-depth modulation, 16 Hz low-depth modulation and 16 Hz high-depth modulation. It was hypothesized that a 16 Hz rate would produce the best effect on performance compared with the two other rates and a non-modulated condition. This was hypothesized because 16Hz directly correlates with beta-band cortical activity and sensorimotor functions. [Engel and Fries, 2010]. Along with results from this experiment, I found other research that backs this theory. The work by Kucikene and Praninskiene presents that different frequencies are categorized into delta, theta, alpha, beta, and gamma, and all have unique effects on the brain and cognitive functions. [Kucikene and Praninskiene , 2018]

It was also hypothesized that either an intermediate or very high depth would yield the best results. This is due to the fact that higher modulation depths are shown to impact neural oscillations. The results from the experiment show that the most effective condition was the 16 Hz amplitude modulation at a moderate depth, since none of the other amplitude modulation conditions appeared to have the same effect. The results of the experiment also show that the effect of 16 Hz beta band modulation was most beneficial for participants with moderate-to-high ADHD and those who self-identify as introverts.

2. BACKGROUND

The first step in Wood's experiment was to use the Amazon platform to recruit participants for the study. Originally 1674 people were enrolled, but only 677 from this participant pool were chosen to contribute to the study. Participants were required to wear headphones and could control the volume of the background music being played. The background music was based on two musical tracks relating to the three modulation rates of 8, 16, 32 Hz and low, medium, and high depths. The study researchers chose to test these three amplitude modulation rates because they all fall within ranges of neural oscillatory regimes that are connected to different functions in the brain. These specific rates were also chosen because they directly correlate to 16th, 32nd, and 64th note values since the music used was set to 120 bpm.

An acoustic analysis was performed on the original music and then that with added amplitude modulation. The analysis confirmed that the manipulated parameters of the amplitude modulation only changed the modulation domain of the original track and didn't affect the audio frequency spectrum. This means that the musical content and EQ was identical under all conditions, removing any potential factors related to spectral balances or musical content impacting behavioral differences. The participants were given the task in a naturalistic environment and were told that the background music was unrelated to the task, but they should still listen passively. [Woods, Kevin J P, et al., 2019]

Since the main goal of this experiment was to track sustained attention over time, In order to track the participants' level of focus, the Sustained Attention to Response Task (SART) was used. The SART involves a motor response to frequent stimuli; the task consists of 9 digits, 0-9, that appear on the screen and are quickly masked with a circle with a cross. Each digit is presented for 250 ms and is followed by the mask that lasts for 900 ms. The participant is asked to respond by pressing the space bar for every number but 3. The SART is a gold standard in evaluating sustained attention, impulsivity, and mind-wandering behavior, and this can be tracked by an increase in commission error and a slower reaction time. [Robertson et al, 1997;

Helton, 2009; Smilek et al. 2010]. After the task is completed, data is then recorded and divided into 7 columns: name of block, number of block, go or no-go trial, digit, size of the stimulus, response outcome, and reaction time.

Table 1. Data Reference Key: The 7 Columns

Colum	Meaning
1	name of block
2	number of the block
3	go (1) or no-go trial (0)
4	digit (1-9)
5	size of the stimulus (values between 1 and 5, from smalles to biggest)
6	response outcome (0 is error, 1 is correct)
7	reaction time in milliseconds

In the first part of the study, participants were told the experiment would continue running and they could leave when they wanted. What the participants didn't know was that the music actually stopped after 78 minutes. After confirming that 20 minutes was a reasonable cap, in the second part of the study researchers told participants that the experiment would only last 20 minutes and to complete the task for the entire duration.

3. MATERIALS AND METHODS

3.1 Experiment/Research

Although the original experiment used a large sample size of 677 participants to collect the most accurate data, I modified this number to 18 participants. By using a smaller sample size of participants, I will not be able to collect statistically accurate results/evidence but am rather aiming to collect data on average. In other words, although I did not have enough time or resources (compared to the original study) to use a large enough sample size, the performance was still expected to yield average results that correlate with the previously published results of the initial experiment.

As described above, the original study tested two experiments, each with six conditions varying between amplitude modulations at 8 Hz, 16 Hz, and 32 Hz as well as testing different combinations with low, medium, and high amplitude modulation depths. Since I am modifying my replication, there is no need to have multiple tracks with 6 varying conditions. Because the original research concluded that 16 Hz at a mid-depth was most effective in enhancing performance, I chose to manipulate these specific modulation parameters. For my own research, I present two almost identical pieces of background music: one with *no added* amplitude modulation and another with the *added* 16 Hz at a mid-range depth. A mid-range depth is essential because too low of an amplitude depth could cause the listener not to hear it enough to have an effect and too high could be distracting and make it obvious that there is added modulation. The two pieces I created are both approximately 5 minutes in length which correlates with the full length of the SART task I have asked participants to complete during the experiment.

3.1.1 Details of the Experiment

Similarly, to the original study, the participants completed the experiment in a naturalistic environment. However, instead of having the participants complete the study remotely, I hosted them in person. Depending on where I met the participants, the environments ranged from living rooms, bedrooms, office spaces, to classrooms etc. All of which were quiet and had no external distractions. I asked the participants to use headphones in order to control the acoustics in the environment and informed them that they should listen passively while focusing on the task at hand.

Before completing the SART, I asked participants to fill out a Ten-Item Personality Inventory (TIPI) survey and scored it to determine if a participant was a self-proclaimed introvert or extrovert. The first column called "extroversion" indicates low, medium low, medium, medium high, and high to determine each participant's personality scored within a range.

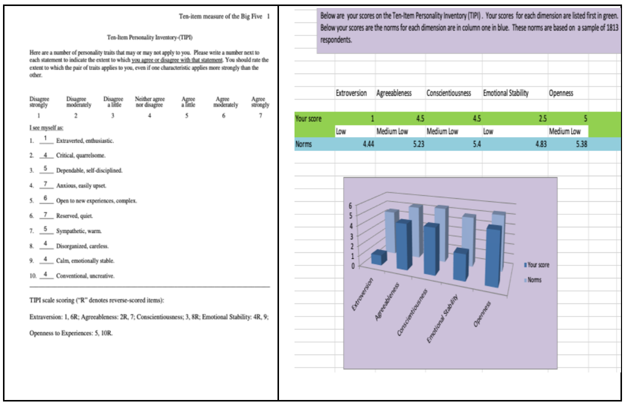


Figure 1.TIPI Questionnaire and Score from participant 2

In order to run the SART experiment, I used PsyToolkit, which is an online toolkit for demonstrating, programming, and running cognitive-psychological experiments and surveys. I chose PsyToolkit after doing research and found that it is frequently used for academic studies and student projects and is a reliable way to collect accurate data. After importing the task into PsyToolkit, I compiled and then ran it twice with each participant. The SART task begins with a training (pre-warm up) round that is implemented to introduce the participant to the task while allowing them a short block to practice.

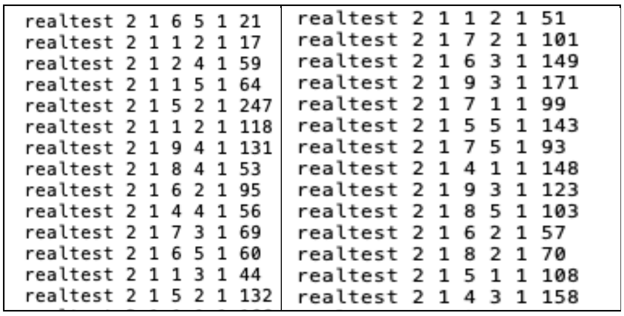
Click here to run a SART demo:
https://www.psytoolkit.org/experiment-library/experiment_sart.html

```
training 1 1 8 3 1 503
training 1 1 6 5 1 594
training 1 1 1 1 1 455
training 1 1 5 4 1 220
training 1 1 9 1 1 123
training 1 1 7 5 1 140
training 1 1 5 3 1 133
training 1 1 1 5 1 120
training 1 1 4 1 1 185
training 1 1 9 5 1 154
training 1 1 2 1 1 174
training 1 0 3 5 1 900
training 1 1 8 5 1 190
training 1 1 6 2 1 173
training 1 1 7 3 1 165
training 1 0 3 4 1 900
training 1 1 2 5 1 30
training 1 1 4 3 1 122
```

Figure 2. Training Block data from participant 2

In order to add variation and rule out any data manipulation between participants, I randomized and varied which track they listened to first (either 1. no added modulation, 2. added modulation or 1. added modulation, 2. no added modulation).

The first trial started with the unmodulated background music being played at a comfortable level for the participant. Around 10 seconds after it began playing, the participant started the SART while I sat out of view to make sure I was not a distraction. The second trial started shortly after, this time an identical track but with added 16Hz amplitude modulation and continued for another 5 minutes. After both trials were complete, I exported the data to separate text files.



realtest 2 1 6 5 1 21	realtest 2 1 1 2 1 51
realtest 2 1 1 2 1 17	realtest 2 1 7 2 1 101
realtest 2 1 2 4 1 59	realtest 2 1 6 3 1 149
realtest 2 1 1 5 1 64	realtest 2 1 9 3 1 171
realtest 2 1 5 2 1 247	realtest 2 1 7 1 1 99
realtest 2 1 1 2 1 118	realtest 2 1 5 5 1 143
realtest 2 1 9 4 1 131	realtest 2 1 7 5 1 93
realtest 2 1 8 4 1 53	realtest 2 1 4 1 1 148
realtest 2 1 6 2 1 95	realtest 2 1 9 3 1 123
realtest 2 1 4 4 1 56	realtest 2 1 8 5 1 103
realtest 2 1 7 3 1 69	realtest 2 1 6 2 1 57
realtest 2 1 6 5 1 60	realtest 2 1 8 2 1 70
realtest 2 1 1 3 1 44	realtest 2 1 5 1 1 108
realtest 2 1 5 2 1 132	realtest 2 1 4 3 1 158

Figure 3: Separate data text files

Figure 3 shows data text files contain all 7 columns, two of which are needed for analysis.

After completing the task, I asked the participants for any additional comments and if they noticed any changes in how they felt during each trial. Many participants could sense a difference in their state of relaxation and concentration during and after trials.

3.2 Musical/Technical

In my modified research experiment, a high arousal and low energy piece was created and used, with an intention for it to invoke positive emotions in the listener while being simultaneously relaxing. My piece was written in the key of A and is tuned to 432 Hz. Similarly, to what was described in the abstract, based on research, 432 Hz tuned music is associated with a slight decrease of mean blood pressure values. [Diletta, 2019]

The goal for this piece of music was to create a song that I would personally use as a study aid. What is considered “effective” background music is subjective and different for each individual. Some people find high arousal and high energy pieces to be most effective, while others prefer those with low arousal and low energy etc. As someone who is more on the hyperactive side, I struggle with music that has strong rhythm and any sort of percussion, whether it’s simple or complex. I find myself most focused while listening to soothing, quiet tracks that resemble the natural or enhanced sounds of my environment. The piece I created is at 120 bpm since this is the exact bpm of the tracks that were used in the original study by Woods et al. Most of the musical guidelines I set for myself were implemented with backing from scientific research and from personal creative preferences.

From a technical standpoint, there are two common ways to add amplitude modulation to any musical piece. One being through a plug-in on a Digital Audio Workstation (DAW) that allows direct manipulation of parameters. Another way to add this modulation effect is by using a visual programming language i.e. a Max/MSP patch. After creating my multitrack piece, I chose to use a MAX/MSP patch that allowed me to open my ambient song file, add and change the amplitude modulation directly on the patch. I found that this option was more precise and enabled me to achieve 16 Hz while also being able to adjust the depth to a mid-range. Another influence on my decision to choose to MAX/MSP was that during the production stage of my experiment, I encountered a limitation within my DAW. I wasn’t able to identify any free plug-ins that were specifically designed for amplitude modulation and provided exact parameters required to manipulate the audio for the purpose of my investigation.

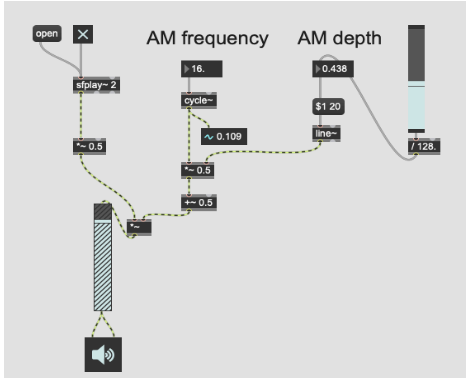


Figure 4. Max/MSP Patch

In Figure 4 there is a patch used to add Amplitude modulation and adjust the depth to one of the musical tracks.

4. DISCUSSION

Using a study that had already been conducted meant that I had a reference for the outcome of my data. The results of my experiment conclude that added amplitude modulation at 16Hz with a moderate depth rate does in fact influence sustained attention and help promote focus. The results also show that people who self-identify as introverts are more reactive to the changes in music with added modulation. As previously mentioned in the “Background” section, the data was recorded and divided into 7 columns. The only columns of interest to me were response outcome and reaction time. From the response outcome, I could count how many errors the participants were making throughout the entirety of the SART. The more errors that are made indicates mind-wandering or lack of focus. Reaction time was also important to see how concentrated and reactive participants were. However, I did note that some participants had slower or faster reaction times in general due to different variables such as, wanting to be more meticulous, experience with computers, age, and any diagnosed or undiagnosed hyperactivity disorders.

Overall, across all 18 of my participants, the average reaction time while listening to non-modulated music was 210 ms compared to 189 ms as the average reaction time while listening to the track with added modulation. From this, it can be inferred that some participants were more concentrated and efficient while listening to the music with added amplitude modulation, with 15 out of 18 participants reacting quicker. After documenting the response outcomes, the average across all 18 participants for the track with no added modulation was 8 errors compared to 6 while listening to the track with added modulation.

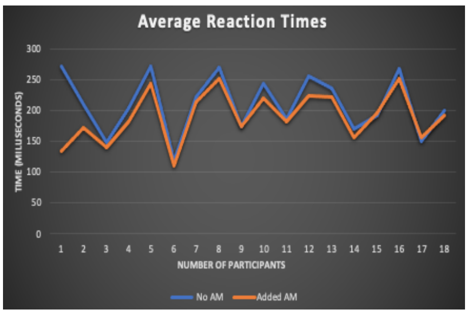


Figure 4. Graph of Average Reaction Times

In figure 4 there is a visual representation of the data, showing that per each participant there was a reduction in reaction time while listening to the track with added amplitude modulation.

Along with the average reaction times being recorded per participant and as a collected, it was hypothesized that there would be less variability in the reaction times after listening to the modulated track. In order to do this, I calculated the coefficient of variation (CV) to ensure the data was accurately reflecting an improvement in change overtime. By examining both the average and CV, it is confirmed that the song with added amplitude modulation elicits a quicker response from the participant, as well as the consistency and reliability of the results. Although it is recommended to calculate the CV for every 10 reaction times over the course of one trial, this would need to be performed around 20 times for 36 trials in total. My approach was to calculate the CV for every 2 trials per participant which yielded less quantitively discrete information, yet the same general results. Typically, if there is inconsistency in reaction times, with it varying between quick and slow hits, this indicates mind wandering and failure of cognition.

The goal of my replication was not to challenge the results of the original experiment but rather to further back them up, all while getting experience with personal research. The results from the data I collected were no surprise; my hypothesis aligned with that of the original experiment and I assumed a similar outcome. However, I did account for the fact that not all data could be accurate, especially since my replicated experiment is heavily modified. In an alternate scenario, if the data didn't align with that of the original study, I was prepared to evaluate the errors and differences that could've drastically changed the outcome of my results. Inaccurate data is also common in research. We don't always get the results and answers we're looking for, and that's the beauty of research.

It is important to acknowledge the limitations of my modified experiment and factor them into my analysis. This includes the amount of time that was available to conduct the experiment, the number of participants, and the overall length of my experiment. The original study ran consistently for 20-78 minutes, whereas mine ran for 10 minutes with a short pause in-between both trials. Although my experiment ran significantly shorter, I received feedback from almost all my participants that it felt longer than 10 minutes. Due to the fact that I was not paying participants like the original study ($0.01 per correct answer and $0.10 per commission error, misses received $0, and an average of $12 for overall task per participant), I believe they were less incentivized to stay committed throughout the entirety of the experiment. I recruited volunteers and chose to not compensate anyone based on the relatively short duration of my experiment.

The original study tested 677 participants compared to the 18 that I had volunteer. I didn't have enough participants to get the most in-depth, accurate data, yet still had enough to see a consistent trend in the data I recorded. My experiment being a shorter duration could have inhibited data that points to how modulation affects cognitive function *overtime*. However, five minutes per each trial (ten minutes in total) was sufficient enough to yield substantial results.

One part of the original study I was not able to factor into my research was how modulated music could be more beneficial for people with inattention or hyperactivity disorders (such as ADHD or ADD). Due to the fact that I was not hosting participants in a professional environment with prior consent documentation, I did not want to infringe on anyone's personal boundaries and collect medical information without the proper authorization.

5. CONCLUSIONS AND FUTURE WORK

As someone who loves both music production and research related to music cognition, I decided to create a project that combines both elements. This project has allowed me to get hands on experience doing my own research as well as working individually with participants. I also have an interest in data analysis, so I enjoyed engaging with both the qualitative and quantitative aspects related to my project. Not only did I get experience working hands on with research and data, the project also presented an opportunity for me to hone my production/mixing skills and create an everlasting piece that I can listen to and share outside my research. Post capstone, I have already discussed a potential deal with an author to publish my song in a new book about musical journeys.

My research project did in fact go as expected and was a great opportunity to combine all of my interests. I focused the majority of my time on the process and creation of my music and research because I assumed the data would match that of the original study. I have become more comfortable running and organizing experiments which will help me in the future to use my new-found skills and confidence to create my own research experiments. Post-graduation I plan to continue exploring the intersection between the mind, body, and music and I may pursue a master's in music cognition or music therapy. I began this project knowing my greatest passion is composing, recording, and producing music but was encouraged to step outside my comfort zone. I am so grateful to have been supported through this project as it has allowed to feel more confidence in my abilities and has helped shape the direction of my future academic endeavors.

5. ACKNOWLEDGMENTS

Thank you to all my participants, my family, Professor Zappi and Professor Loui!

6. REFERENCES

[1] Diletta Calamassi a, et al. “Music Tuned to 440 Hz versus 432 Hz and the Health Effects: A Double-Blind Cross-over Pilot Study.” *EXPLORE*, Elsevier, 6 Apr. 2019, https://www.sciencedirect.com/science/article/pii/S1550830718 302763.

[2] Palmiero, M., Nori, R., Rogolino, C., D'Amico, S., & Piccardi, L.(2015). Situated navigational working memory: the role of positive mood. *Cogn Process, 16 Suppl, 327-330*.

[3] Thompson, W.F., Schellenberg, E.G., and Letnic, A.K. (2012). Fast and loud background music disrupts reading comprehension. Psychol. Music 40, 700-708.

[4] Kučikienė D, Praninskienė R. The impact of music on the bioelectrical oscillations of the brain. Acta Med Litu. 2018;25(2):101-106. doi: 10.6001/actamedica.v25i2.3763. PMID: 30210244; PMCID: PMC6130927.

[5] Smilek, D., Carriere, J.S.A., and Cheyne, J.A. (2010) Failures of sustained attention in life, lab, and brain: Ecological validity of the SART. Neuropsychologia 48, 2564-2570.

[6] *Sustained Attention to Response Task (SART)*, https://www.psytoolkit.org/experiment-library/sart.html.

[7] Woods, Kevin J P, et al. “Modulation in Background Music In- fluences Sustained Attention.” *ArXiv.org*, 16 July 2019, https://arxiv.org/abs/1907.06909