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Bryndís Harpa Björnsdóttir og Sigríður Ásta Pedersen

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12 eininga lokaverkefni

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Útdráttur

Heilinn er einstaklega margslungið líffæri, sem meðal annars þjónar þeim tilgangi að hýsa minnið. Þegar virknin í heilanum virkar eins og samstilltar sveiflur, kallast það heilabylgjur og eru þær flokkaðar eftir tíðni þeirra. Sérstakur áhugi var fyrir gamma bylgjum, þar sem tíðnin sveiflast á milli 30-100 Hz (Bear et al., 2016; Jia and Kohn, 2011; Tichko et al., 2020). Samkvæmt rannsóknum hafa gamma bylgjur í heilanum margvísleg áhrif og eru truflanir á þeim algengar í ýmsum sjúkdómum t.d. geðklofa (e. schizophrenia) og öðrum lyndisröskunum (e. mood disorders) (Gonzales-Burgos et al., 2015; Fitzgerald and Watson, et al., 2018). Í þessari rannsókn skoðuðum við því sem haldið er fram á ýmsum vefsíðum og bloggum hjá t.d. Diaz (2019) um að gamma bylgjur séu tengdar jákvæðum áhrifum á endurheimt, hamingju og einbeitingu, þessi áhrif á að vera hægt að örva með sérstakri tónlist sem einblínir á að örva gamma bylgjur. Sérstaklega veltum við því fyrir okkur, hefur gamma bylgju tónlist áhrif á minnið?

Vegna aðstæðna í samfélaginu (COVID-19) þurfti þessi rannsókn að vera gerð á Internetinu. Þátttakendur voru fengnir í gegnum síðuna *Prolific* og voru 59 einstaklingar (n=59) sem kláruðu rannsóknina en taka þurfti hana í tveimur lotum. Þeim var handahófskennt raðað niður í þrjá hópa og allir látnir lesa tvær smásögur og svara satt eða ósatt spurningum upp úr þeim en einnig reyna leggja á minnið nokkur orð úr stuttum orðalista. Á meðan á rannsókn stóð fékk einn hópur gamma tónlist, einn hópur fékk hljóðfæratónlist (ekki gamma) en þriðji hópurinn fékk enga tónlist til að hlusta á. Núlltilgátan var sú að gamma tónlist hefur engin áhrif á minni. Bayes þátturinn sem notaður var sem stöðvunar viðmið við gagnasöfnun var 3 með eða á móti núlltilgátunni.

Niðurstöður úr fyrri og seinni lotunni voru svipaðar og sýndu fram á engan marktækan mun á milli hópa. og því er hægt að segja gamma tónlist hafa engin áhrif á minni. Niðurstöður okkar rannsóknar gefa til kynna, í þessu samhengi, að tónlist sem á að auka gamma bylgjur hafi engin áhrif á frammistöðu minnis.

Abstract

The human brain is an extremely complex biological structure that, amongst other functions, serves as the substrate of human memory. When brain activity fluctuates in a synchronised manner, the result is brain rhythms or waves, which are defined by the frequency of this activity. Of particular interest are gamma waves, which occupy frequency ranges from 30-100 Hz (Bear et al., 2016; Jia and Kohn, 2011; Tichko et al., 2020). According to the literature gamma waves have different kinds of effect, and disturbances in gamma wave activity have been found in many diseases (e.g., schizophrenia and mood disorders; Gonzales-Burgos et al., 2015; Fitzgerald et al., 2018). In the study reported here, we addressed the claims made on a variety of lay blogs and websites (e.g., Diaz, 2019) that gamma waves are associated with positive effects on recall, happiness, and focus, and that these effects can be induced by certain types of music purporting to stimulate gamma-wave activity. In particular, we asked: Does "gamma wave" music have an impact on memory?

We conducted an online experiment (necessitated by the circumstances resulting from the COVID-19 pandemic) to test this possibility. Participants were recruited through the online research platform *Prolific* and 59 participants completed the study across two experimental sessions. They were randomly allocated into three groups and had to read two short stories (followed by with true and false questions about the stories' contents) along with completing a word recognition task. One group listened to gamma music while learning both sets of materials, one listened to control (non-gamma) instrumental music, and a third group did not listen to any music. The null hypothesis was that gamma music has no effect on memory. The Bayes factor used as our stopping criterion for data collection was a value of 3 in favour of, or against our null hypothesis.

Results from the first and second session were very similar and showed evidence against any differences between the groups. Our study thus suggests that, at least in this context, music purporting to induce gamma activity has no effect on memory performance.

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We want to deeply thank our supervisor, Peter Shepherdson, for great patience, understanding and amazing leadership. He was very helpful and kept us motivated the whole time. We are grateful for the opportunity to work with him on this very interesting subject.

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Assessing the effects of "Gamma music" on memory[1]

Memory

In a time-poor society, the ability to learn as rapidly and effectively as possible is highly advantageous, so for the past decades many different methods for optimizing learning have been proposed. One strategy toward this end has been to investigate what brain states and characteristics are associated with effective functioning of the systems used in learning. For instance, findings showing that certain brain rhythms may be connected to the use of the working memory system has led to interest in the consequences of inducing these rhythms. In this study we will be building on this foundation by investigating whether a certain type of music, purported to stimulate gamma oscillations ("gamma music") positively affects learning and memory performance. Before describing the study, we first review relevant literature pertaining to memory, brain rhythms, the connections between brain rhythms and relevant psychological phenomena, and claims made about their stimulation by certain forms of music.

The human brain is an extremely complex biological structure, among the functions of which are to serve as a store for our memories. Human memory can be classified in a number of ways, including through the definition of different systems that serve varying memorial functions, such as, working memory, short-term memory, and long-term memory (Bear et al., 2016, p. 828). Short-term memory is very confined capacity wise, both storage and how long it lasts (Cowan, 2008). Eventually memories get erased or go through a process called memory consolidation to go in long-term memory, but from there they can be recalled when required (Bear et al., 2016, p. 828). Working memory has limited capacity that varies between individuals and is usually around 4 items that are kept "in mind" for a very short amount of time; if rehearsed enough it will go through memory consolidation getting into long-term memory (Bear et al., 2016, p. 829; Cowan, 2000). According to Ding et al. (2019) using an electroencephalography (EEG) displayed while listening to music, the gamma waves responded first in the sensory cortex leading to the frontal cortex where according to Bear et al. (2019) the working memory is located. Whether there is a connection between gamma waves and music is not known for certain.

[1] The introduction section is in part based on contents from a pre-registration document co-authored with Peter Shepherdson (Björnsdóttir et al., 2021), uploaded to the Open Science Framework (https://osf.io/thgpc/).

Brain rhythms and gamma waves

Brain rhythms refer to the synchronized fluctuation of activity across different parts of the brain (Jia and Kohn, 2011). Such rhythms in the cerebral cortex are typically recorded through the scalp or directly from the brain [e.g., with an electroencephalogram (EEG) or magnetoencephalography (MEG); Jia and Kohn, 2011; Bear et al., 2016, p. 646], and are distinguished on the basis of their frequency. For signals to be strong enough to be detected by EEG thousands of neurons must activate together, and the rhythms with which they do can range from 0.05 Hz to 500 Hz, and maybe more (Bear et al., 2016, pp. 647, 650). The main rhythms recorded by EEG are Delta, Theta, Alpha, Beta and Gamma, and are associated with various cognitive phenomena (Bear et al., 2016, p. 650).

Of particular interest in this project are gamma rhythms, a form of activity with a relatively high frequency. The specific frequency range attributed to gamma rhythms varies in the literature, is most commonly described as occurring between 30 and 100 Hz (Bear et al., 2016; Jia and Kohn, 2011; Tichko et al., 2020). A substantial amount of research has been conducted into the properties of gamma waves, which have been implicated in positive effects on systems such as working memory and attention (Jia and Kohn, 2011). Further, Tichko et al. (2020) have suggested a positive connection between music that stimulates gamma activity and memory, proposing music-based interventions as a component of potential non-invasive treatment to improve cognitive functioning in patients with dementia-related disorders.

Gamma oscillations and psychological disorders

Literature can be found connecting gamma rhythms with various clinical phenomena, mostly with decreased oscillations in some parts of the brain. For instance, some difference has been found in gamma activity over brain regions between a variety of mood disorders (Fitzgerald and Watson, 2018). One of the effects of Ketamine, which is found in many antidepressants, is to increase gamma oscillations in various parts of the brain which seems to have positive effects on people with mood disorders (Fitzgerald and Watson, 2018). The location where there are disturbances in gamma oscillations differ between unipolar and bipolar patients, therefore gamma rhythms seem to be connected to depression and may be a compliance with treatment response (Fitzgerald and Watson, 2018). According to Gonzales-Burgos et al. (2015) parvalbumin neurons play an important role in gamma oscillations but in

patients with schizophrenia these neurons show molecular alterations. Numerous EEG and MEG studies have reported disturbance in gamma oscillations in frontal cortical regions along with lower gamma rhythms in dorsolateral prefrontal cortex (Gonzales-Burgos et al., 2015). This disturbance affects working memory and cognitive control in patients with schizophrenia (Gonzales-Burgos et al., 2015). Research on Autism spectrum disorder has also shown differences in gamma oscillation in EEGs from frontal and parietal recording sites which has led to research on treatment options using Transcranial Magnetic Stimulation therapy (TMS) (Casanova et al., 2020). In a study by Casanova et al. (2020, p.14) they concluded after TMS treatment that the participants' gamma responses significantly reduced along with their errors doing cognitive tasks in the study and mentioned that "gamma oscillations play a crucial role in the binding of information between neural networks". Research about amnestic mild cognitive impairment by Vanneste et al. (in press) showed clear decrease in gamma oscillations and density in the posterior cingulate cortex, extending to the retrosplenial cortex and the parahippocampal. Vanneste et al. (in press) used two assessments in their research, California Verbal Learning Test II (CVLT-II) and Delis Kaplan Color Word Interference Test (D-KEFS), where decreased gamma oscillations showed an effect on the altered cognitive performance. In literature it is apparent the need for more research on gamma rhythms' effect on the brain, to better understand what role they may play in different types of disorders; but it seems like disruption on gamma oscillation can have a variety of effects on cognition. Compared to the research above, gamma oscillations are very important for the brain to work properly and disturbances can have various kinds of consequences. Vanneste et al. (in press) show disturbance in MCI, one might think improving gamma oscillations could increase memory performance and as can be read later in the following chapters it seems to be a possibility.

Gamma waves and music

Music is universal and has been a part of mankind for thousands of years. It cannot be said with full certainty when music was first invented, but the oldest known instrument found in excavation was around 40,000 years old (Killin, 2018), implying that music has been with us for a long time. In a research by Griffiths et al. (2002) on analyzing brain networks they found that the brain reacted to any kind of sounds, pitches, rhythmatics and melodies. Music is a combination of different types of sounds that has developed and been a part of various social events and forms of entertainment over the centuries. Accessibility to music has

become easier with more technology and therefore the amount of people listening to music has increased and it is used more in everyday life (e.g., while doing housework, cooking, cleaning, and driving; Jakubowski and Ghosh, 2019). Music is often used to express many things, frequently including emotions (e.g., love or a memory of love; North and Hird, 2020). Ding et al., (2019) concluded that both hemispheres produced gamma-wave activity while people listened to music, with stronger responses in the right hemisphere. Listening to music leads to emotional responses but the right hemisphere also retains emotions (Gainotti, 2018). Researchers have demonstrated an enhancement in autobiographical memory as a result of listening to music, mostly from classical and popular music genres (Jakubowski and Gosh, 2019). Specifically, though people experience autobiographical memory at least once a day regardless if they listen to any music at all, with music they will experience it more frequently (Jakubowski and Gosh, 2019).

The possibility that music-induced gamma activation might benefit cognitive functioning has also been highlighted outside of the peer-reviewed literature. Some sources have focused on the stimulation of gamma activation through the use of "binaural beats", in which "a different frequency of music, measured in hertz (Hz), is played into each ear, say 120 Hz in your right ear and 110 Hz in your left ear", purportedly resulting in a coordination of brain waves into gamma (or other) rhythms (Colorado State University Global, 2019). This induced rhythmic activity is then claimed to benefit a variety of cognitive processes, depending on the specific rhythm triggered (Colorado State University Global, 2019), presumably which extend beyond the affectively pleasing impact that various forms of music can have (Musliu et al., 2017). Despite such claims being widespread on the internet (e.g., Colorado State University Global, 2019; Diaz, 2019; Smith, 2019), the empirical evidence supporting them appears scarce. Though there is evidence indicating that gamma activity is associated with memory and attention (see, e.g., Nyhus and Curran, 2010; Tichko et al., 2020), experimental manipulations of gamma activation through musical stimuli which show beneficial effects on cognitive performance are practically non-existent. One exception to this comes from a recent small-scale exploratory study by Sharpe et.al. (2020), whose research showed some enhancements in memory, mood, and cognition, following the presentation of 40 Hz binaural beat stimuli. However, given the sample size Sharpe et al. used (3 participants per group), the reliability of these findings is questionable.

The present study

According to a blog post written by Diaz (2019), "people with very high levels of gamma activity are exceptionally intelligent, compassionate, and have strong self-control. IQ scores of people with high gamma wave activity are correspondingly high", and gamma activity leads to benefits such as enhanced recall, sensory perception, focus, processing speed, happiness, and creativity. Rather than being an outlier, this reflects a broader characterisation of the effects of gamma activity spread in online sources (e.g., Colorado State University Global, 2019; Diaz, 2019; Smith, 2019). Along similar lines, videos containing music purporting to enhance gamma activity have received millions of views on video sharing websites such as YouTube, if interested see links in footnote[2]. This suggests that a public perception concerning these effects exists which substantially exceeds the claims justified by the currently available scientific literature on the topic. In the present study, we addressed this disconnect by directly investigating the impact of "gamma music" on memory for different types of material. Specifically, we ran an experiment in which we compared the memory performance of three groups of participants, who studied verbal materials while being exposed to no music, "gamma music" (i.e., music purported to produce gamma rhythms in the brain), or control (non-"gamma") music. In doing so, we aimed to determine whether the relevant claims being made in the blogosphere are justified.

[2] https://www.youtube.com/watch?v=9pJheICAck4; https://www.youtube.com/watch?v=vLEek3I3wac; https://www.youtube.com/watch?v=EVPLIZotdrg

1. Method[3]

1.1. Participants

Participants were recruited through the online research platform *Prolific* (prolific.co) and they received a small payment for their participation in two experimental sessions, with compensation of £3.75 after the first session and £1 for the second session (i.e., a total amount of £4.75 for those participants who completed both sessions). The duration between the two sessions was at least 48 hours. The research was limited to individuals over the age of 18. A total of 84 signed up, only 59 completed the first session of the experiment and therefore 25 participants were excluded. The mean age in the first session was almost 37 that ranged from 18-64 years old. The sample consisted of 57.6% females (n=34) and 42.4% males (n=25). Research was also limited to individuals speaking English as a first language, and residing in predominantly English-speaking countries with 86% from United Kingdom (n=51), 6.8% from Ireland (n=4), 1.7% from Canada (n=1), 1.7% from United States (n=1), 1.7% from New Zealand (n=1) and 1.7% who did not provide an answer (n=1). Participants were asked if they were students and 23,7% answered yes (n=14) and 76.3% answered no (n=45). Only 50 participants finished both sessions, average age in that group was 34,8. Male were 46% (n=23) and female 54% (n=27).

Expectations of having 50 participants in each group could not be achieved which was of little importance since we reached our Bayes Factor-based stopping criterion with definitive results with barely 60 participants (n=59). Our criterion for stopping was a Bayes factor of 3 in favour of, or against, a model incorporating a difference between groups.

1.2. Materials

This study was created using PsychoPy (Peirce et al., 2019). In two conditions, participants listened to music during an initial learning phase. For one group, this was "gamma wave" music, purported to induce gamma activity. We obtained this music from the audio track of a popular YouTube video at (https://www.youtube.com/watch?v=vLEek3I3wac&t=2576s). Another group listened to control music, selected during a pilot study for its similarity to the "gamma" music on the five dimensions identified by Živanović et al. (2018). In the pilot study, 15 participants listened to 2-minute excerpts of predominantly instrumental music and rated them on sliding

[3] The method section is in part based on contents from a pre-registration document co-authored with Peter Shepherdson (Björnsdóttir et al., 2021), uploaded to the Open Science Framework (https://osf.io/thgpc/).

scales pertaining to these five dimensions. Three of the excerpts were different tracks of "gamma" music, with the remainder being Western art music from various periods (renaissance to contemporary). We then selected the examples of "gamma" and other music that were rated the most similar, as indicated by inverse summed distance across the five dimensions.

Two types of memory materials were used in this study. The first involved two short stories (or excerpts thereof), taken from contest entries at the writing website reedsy.com, and each story was between 1000 and 1500 words in length. We created 20 true/false questions pertaining to the content of each story, 10 each for use in a memory test in the initial and second sessions. The second type of memory material used was a list of 20 1—2 syllable concrete nouns. Half of these words appeared on a memory test during the initial and second sessions, along with 10 unique lures fulfilling the same criteria. All words, stories and questions are listed in the Appendices.

1.3. Procedure

In the initial session, after completing a consent form, participants completed a headphone screening test (Milne et al., 2020) to ensure correct functioning of their sound system. Following this, all participants read two short stories, and were then presented with a list of 20 words in serial order, with a presentation rate of 3 seconds per word. During the presentation of the stories and word list, the participants were exposed to different sound conditions, depending on a random initial allocation to groups. One group listened to "gamma" music during the presentation; a second group listened to control music; and a third received no audio input at all. Following the presentation, participants were initially tested on their memory for the story content, involving 20 true/false questions (10 per story). Each question was a statement describing an event that either did or did not occur in the story, with participants asked to identify the true and false statements. Finally, they had to complete a recognition test on their memory for the word list, involving 20 words where 10 of which appeared in the initial list, and 10 of which did not.

At least 48 hours later, participants were asked to complete a second session, with the duration between completion of the first and second session ranging from just over 48 hours to approximately one week. The second session involved memory tests analogous to those

completed during the first session, but with different stimuli used during the tests (e.g., the 10 words from the initial list that were not tested during the first session were tested during the second, along with 10 new lures).

1.4. Data analysis

All data were analysed using R (R Core Team, 2020) and the *brms* package (Bürkner, 2018). Bayesian regression was used to analyse responses to the word list and story-based memory test questions for each session separately. In this analysis, we used group (gamma vs. control vs. silence) as a fixed effect, and material type (story vs. word list) as another. We also incorporated random effects of participants and questions into the model. These effects were used to predict the signal detection theory measures sensitivity (*d'*) and bias (*c*) through a Bernoulli-logit model. We suppressed the intercept and set Normal (0.5, 2.5) priors on *d'*, and Normal(0, 1.5) priors on *c*, for each condition. To evaluate whether there were any differences in memory performance across the three groups, we used the *hypothesis()* function in *brms* to estimate Bayes factors using the Savage-Dickey density ratio method. Specifically, we evaluated the evidence relevant to the hypotheses that performance (indexed by *d'*) was equivalent across the groups, in a series of paired comparisons: Evidence in favour of this hypothesis suggests that performance across the two groups used in the comparison does not differ, whereas evidence against the hypothesis suggests that it does. If music advertised as promoting gamma-wave activity does improve memory performance, we expected to see higher values of *d'* for the gamma group across both sets of memory materials (i.e., stories and lists). The Bayes factor used for our stopping criterion for data collection was a value of 3 in favour of, or against, a difference between performance in the gamma music group and both of the other groups. We ended up doing the analyses separately for both the initial and final tests. In addition to these comparisons with the combined data, we also compared performance across groups for the story and word components of the memory test separately, using the same method.

2. Results

2.1. Descriptive statistics

2.1.1. First session

Memory performance was similar across groups in the first session. When answering the true and false statements about the stories, participants in the gamma group (*d'* = 1.96,

95% Credible Intervals = [1.48, 2.48]) showed similar performance to the control music group (*d'* = 1.92, 95% CrI = [1.52, 2.33]) while the silence group (*d'* = 1,79, 95% CrI = [1.43, 2.16]) did slightly worse than other two groups. When it came to the word test the silence group (*d'* = 3.26, 95% CrI = [2.81, 3.74]) performed slightly better than the gamma group (*d'* = 2.97, 95% CrI = [2.43, 3.55]), with the control group performing worst (*d'* = 2,66, 95% CrI = [2.23, 3.11]).

2.1.2. Second session

In the second session when answering the statements, mean sensitivity for the control group ((*d'* = 1.06, 95% CrI = [0.75, 1.39]) was higher than for the silence group (*d'* = 0.80 , 95% CrI = [0.14, 1.07]) and the gamma group (*d'* = 0.78, 95% CrI = [0.44, 1.12]). When observing the word tests results there was a very slight difference between the control group (*d'* = 1.01, 95% CrI = [0.69, 1.33]) and the silence group (*d'* = 0.98, 95% CrI = [0.71, 1.26]), with the gamma group (*d'* = 0.70, 95% CrI = [0.36, 1.04]) performing somewhat worse.

2.2. Control vs. gamma

2.2.1. First session

When comparing performance on responses to the story statements from the first session for the control group vs. the gamma group there was evidence against a difference (*BF* = 6.03) while the lower credible interval (CrI) was -0.69 and the upper CrI was 0.61. For recognition performance on the word list the lower CrI was -1.04 and the upper was 0.41 with evidence against a difference (*BF* = 3.98).

2.2.2. Second session

Second session results from the statement had the lower CrI at -0.19 and the upper at 0.75. There was evidence against a difference between control condition and gamma condition (*BF* = 3.95) which was also apparent with the word test (*BF* = 3.45). The lower CrI in the word test was -0.16 and the upper was 0.78.

2.2.3. Combined across test materials

When combining results across responses to both the story-related questions and word recognition test, the evidence against a difference between the control and gamma groups was consistent, though stronger in the first session than in the second (*BF* = 4.19 vs. *BF* = 2.18). Lower CrI in the first session was -0.76 and upper at 0.39. In the second session lower CrI was -0.06 and upper at 0.66.[4]

[4] Note that, in the second session, performance of those in the Control group was numerically superior to performance of those in the Gamma group.

2.3. Silence vs. gamma

2.3.1. First session

When comparing statement scores from the first session on the silence group and the gamma group there was evidence against a difference (*BF* = 5.65), the lower CrI was -0.78 and upper CrI was 0.44. Word test comparison had also evidence against a difference though slightly lower (*BF* = 4.33). Lower CrI was -0.43 and upper CrI at 1.

2.3.2. Second session

In the second session the statements test had a really high evidence ratio for our null hypothesis (*BF* = 8.92) with lower CrI at -0.42 and upper at 0.45. Testing the word list didn't show a high evidence ratio but still supporting the null hypothesis (*BF* = 4.6). Lower CrI wasn't very low or only -0.15 but the upper CrI was 0.72.

2.3.3. Combined across test materials

When combining results from the statements test and word tests in the first session, there was evidence against the difference (*BF* = 5.64) and lower CrI was -0.49 and upper CrI was 0.61. In the second session the evidence against the difference was scarcely higher (*BF* = 6.23) with a smaller difference between lower and upper CrI at -0.18 and 0.49.

2.4. Control vs. silence

Though not the specific purpose of our study, we also compared performance between the control and silence conditions.

2.4.1. First session

There was evidence against a difference between control group and silence group (*BF* = 6.58) in the first session of the statement test with lower CrI at -0.67 and upper CrI at 0.42. Evidence against a difference was also found in the word list test (*BF* = 1.25) but it was substantially lower than in the statement test. The CrI has the highest lower number so far at -0.03 and the highest upper number at 1.25.

2.4.2. Second session

In the second session of the statement list between control group and silence group, there was evidence against a difference (*BF* = 4.45). Lower credible intervals were -0.68 and upper 0.15. Analysis for the word list in the second session showed a rather high evidence ratio (*BF* = 9.37) supporting the null hypothesis with the lower CrI at -0.46 and the upper CrI and 0.39.

2.4.3. Combined across materials

When combining the analysis for control vs. silence, the second session showed a higher evidence ratio (*BF* = 4.33 vs. 6.26) supporting the null hypothesis. First sessions lower

CrI was -0.27 and upper 0.74. While second sessions lower CrI was -0.47 and upper was 0.18.

3. Discussion

This study was conducted with the aim of finding out if gamma music has any effect on memory. Various studies have been conducted connecting gamma oscillations with many types of diseases though nothing can be said for certain. When browsing the internet, all kinds of blogs and websites can be found praising effects of gamma waves (e.g. on memory) that are at most scarce. When this study was conducted, no other research connecting gamma music to memory could be found which made this topic even more interesting. Due to circumstances (COVID-19) this study could only be done online, making people use their own computers and headphones. We wanted to see if gamma music could have an impact on memory while learning short stories and/or a wordlist. This type of research could tell us if it worked on working memory and long-term memory (pre- and post-consolidation). According to our findings no significant difference was between groups.

3.1 All groups

3.1.1. First session

According to results from the first session we can see that the gamma group had the best performance in the statement test but was second in the word test. The control group showed similar results in that statement test to the gamma group but lacked that score in the word test. Silence group had the worst results in the statement test but higher results in the word test. Findings from the first session show no significant difference between groups on long-term memory pre consolidation.

3.1.2. Second session

The second session results were surprising since the control group did significantly better than in the first session and scored highest in both statements and word tests. Outcome for the silence group and gamma group were rather similar in the second session though gamma did slightly worse. Findings from the second session show no significant difference between groups on long-term memory post- consolidation.

3.2. Exchange of views and speculations

Literature on gamma waves and different types of illnesses is lacking but so far a disturbance in oscillations seems to have considerable consequences for various types of

disorders (Fitzgerald and Watson, 2018; Gonzales-Burgos et al., 2015; Casanova et al., 2020; Vanneste et al., in press). When comparing our findings to Ding et al. (2019) who said listening to music will lead the gamma oscillations to the frontal cortex where working memory is said to be stored (Bear et al., 2016), we can see from our results it has no effect. Vanneste et al. (in press) concluded disturbance in gamma oscillations in the parahippocampus where the long-term memory is located, if gamma music would have worked it might have been good news for patients with MCI. Our conclusion is that gamma oscillations are very important for the brain to work properly, disturbances in rhythms may have a drastic impact on health. Benefits from gamma waves are very widespread on the internet in papers and blogs, with online sources mentioning features such as higher IQ and self-control (Diaz, 2019). However, the evidence on which these claims are based is unclear, and as we have established in the text above there are limited studies on this specific content so none of the claims can really be verified.

Researchers conducting this study were very positive that specific music had any effect, our findings however showed no significant difference between groups with gamma music, control music and no music. Differences between groups weren't as much as expected, especially between the gamma group and silence group. Our findings show that the kind of music we tested on cannot help people while they are studying, in that case we would recommend people listen to whatever music they like while studying if it helps them remember and stay focused and exclude ambient noise.

3.3. Limitation and future research

3.3.1. Limitations

Having a bigger sample might change something or verify better the null hypothesis though we didn’t need more to get good evidence in favour of our null in our research, more data is always better. When conducting our study the situation in our society wasn’t good because of COVID-19, therefore it was necessary to have an online study. We do think it would be better to do this in a more controlled environment to limit impact from the participants' surroundings and supervise quality of headphones and speakers used for the study.

3.3.2. Future research

The gamma oscillations phenomena is something that needs to be more researched since the literature so far seems rather limited. Current studies on gamma oscillations and brain illnesses are intriguing but sadly lacking, more intensive research locating and

inspecting what, where and why these disturbances occur, could be revealing. Similar research to ours could be conducted with an EEG attached to monitor brain rhythms and distinguish if specific rhythms increase or decrease under any circumstances, where in the brain the disturbance is located and also observe if any other memory is utilized. Using an EEG could also verify whether the music purporting does induce gamma activation. Authors speculate if musical interest can affect the outcome since some people are very good at ignoring sounds (e.g., music) if they don't like them. It would be interesting to see if participants would pick the music out themselves, monitor which rhythms they affect and if it helps stimulate any part of the memory for that specific participant. No studies were found on gamma oscillations and attentional-deficit/hyperactivity disorder (ADHD) while working on this research, it raises interest if gamma music has any effect on people with ADHD (e.g., relaxing or concentrating). Since other ailments can be affected by gamma oscillations [e.g., autism spectrum; Casanova et al., 2020] it can be anticipated that ADHD might also be affected, if so these types of research might open new possibilities in treatments for them.

Conclusion

Literature on gamma rhythms is rather unilateral. When it comes to diseases it's important and disturbances have various effects. People have claimed music has many different effects on them, physically, mentally and emotionally (Jakubowski and Ghosh, 2019; North and Hird, 2020). Without evidence, many spread rumors about gamma music having a positive effect on memory. This study was conducted online through the website *Prolific* and without much participation, it provided evidence in support of the null hypothesis that gamma music has no effect on memory. According to our findings gamma music has no effect on working memory or long-term memory. We believe this subject needs to be more researched since gamma oscillations in the brain are very fascinating and can have various effects.

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Appendix A

Stories

First story

"Sir? Excuse me. Sir?"

I blinked back the tears that were beginning to prick my eyes, causing the broccolis and carrots to judder and blur before me into a psychedelic haze. When I could trust my features not to betray my emotions to my interlocutor, I began to shuffle round. I was expecting someone of my height or taller, as was more often the case these days, due to my danged stoop. I only saw a row of cauliflower where a head ought to have been before I dropped my gaze to see concerned grey eyes peering up at me.

"Y-yes?" I asked the lady. I put her to be about ten years younger than me, going by the plastic indigo clogs peeping out from beige slacks, the veins and wrinkles of the hand on her basket, the puckered mouth. Her snow white hair was swept into a girlish ponytail. I couldn't tell whether her pencilled brows were raised in alarm at me or because of the hairstyle.

"I couldn't help noticing…you've been staring at that empty crate for a while…"

"Ah. Yes." I rubbed the back of my neck like I always do when I'm caught out.

She continued, "I thought perhaps I could help you find what you're looking for. I don't work here, but I sure am in here enough!" She laughed, causing her laugh lines to deepen and me to wonder when a woman last had cause to laugh in my company. Since Arabella passed away, it had mostly been just the women on the TV or radio making that sound.

"So what was it?"

"Ah, yes, well, that would be the radishes…" I looked down at my list, which my hand, unbeknownst to me, had crumpled into a tight little ball. "Radishes and rocket. That's what she liked in a side salad, and I get here, only there are no radishes, and…" I stepped out of myself for a second and saw how much of a babbling moron I looked. Luckily, Grey Eyes took the reins.

"Well, you're in the right place. That's where they'd be." Her voice softened a touch. "Looks like you're out of luck this time."

"Guess so," I agreed. I'd been out of luck since a heart attack stole Arabella from my life four years ago.

"How about a substitute? What about a turnip? Or a carrot, plenty of those right there. Or perhaps beetroot, or…"

She trailed off. Musta spotted my face crumpling up like that bit of paper.

I cleared my throat. “I’m sorry. I know I must seem ridiculous. It’s just, it’s my wife and mine’s anniversary today and I like to fix her favourite thing for dinner. It’s just my little way of remembering her. And now there aren’t any radishes…” I pointed an accusing trembling finger at the uncaring green emptiness. “It just feels like I’m letting her down. Disappointing her. Again.”

“Oh, honey.” She patted my sleeve. I focussed on her lovely pearlescent nails, dazzling under the awful strip lighting they put in these places. Then I examined a scuff mark on one of her shoes until I was ready to look up again.

“You don’t need this shit anyway,” she swung her basket around, condemning row upon row of veg like a malevolent judge. A nearby mother of two who was weighing up an avocado frowned at us.

“Wh-what do you mean?” I asked.

“This stuff and nonsense, all treated with chemicals, wrapped in plastic…listen, I’ve got an allotment. You come and taste some of *my* radishes, see if ya go back to this processed garbage.”

A strange woman inviting me to sample her produce. This was indeed an auspicious meeting.

“Hah!” she cried. “Got you smiling there, didn’t I?”

“Heh, yup. But how comes you’re in here then if homegrown’s so good?”

She lowered her voice conspiratorially, or what she considered low anyway. Although her eyes still twinkled and her hair shone, it seemed her ears had been the first to give up.

“My nephew Stu works here. I get a good family discount on my favourite amaretto. I haven’t been able to perfect the ingredients for *that* in the allotment, although not for lack of trying, lemme tell you.”

We both chuckled at that. Felt weird to have transitioned from ‘old guy crying over radishes’ to ‘schoolboy giggling over drinks’ so rapidly.

Next thing I knew was that Grey Eyes was taking me by the arm to go find the nephew (she gave him a scolding about not keeping the root vegetables well-stocked, waving away his protests that it wasn’t his fault and probably something to do with Brexit) and I was getting into my car with a new number in my phone. Marion. I blinked dumbly at the name for about a minute before tucking the phone with its precious new cargo safely in the glovebox. I set off for home with a lighter heart than the one I took out with me.

When I got my house keys out ten minutes later though, that lightness had ebbed away, being replaced with a flood of guilt, annoyance, fear and impatience. As I fumbled with the lock I wondered how I would face her tonight. I was peeved the extended waltz around the

supermarket had made me miss the beginning of my show. I was scared to feel things I thought had died with Arabella that day.

"Bloody lock!" Cursing at it seemed to be the open sesame.

I heard voices coming from inside. Voices I didn't recognise.

Because I'd left the TV on (Arabella drilled that into me, scares away potential intruders, she claimed) and I'd missed my show.

I stared at the unfamiliar characters on the screen. A mother telling her daughter that perhaps it was time to move on. That prompted me to find the clicker and turn the damn thing off.

In silence I put the shopping away, pausing on a bottle of hot sauce Grey Eyes – no, wait; *Marion* had enthused about before throwing into my basket. It went to the back of a cupboard, to stand meekly behind a bottle of sunflower oil and a jar of basil.

I could feel her watching me.

I washed up a few bits from lunch and got the oven warming up. I poured myself a glass of water into a glass that was too small. I transferred the water into a bigger glass and topped it up with more.

I could faff no longer. It was time to face her.

But first I had to pour this stupid water into a plant and fix myself a whiskey instead.

I carried the tumbler over to the dining table, where she waited. She seemed to understand about the alcohol, waiting patiently while I lowered myself onto the chair with a groan. Can't seem to stand up or sit down these days without adding vocals to the percussion of cracks and pops my old bones made.

I sipped my drink and savoured her beauty awhile. My shining bride, head tilted to look up at mine, me grinning like a goon who's holding a winning lottery ticket.

Yet she was priceless.

I told her about my day, how I'd frozen in the fruit and veg aisle, how a kind passing stranger had kicked me to get me going again. She didn't say anything, but when you've been together as long as us the right kind of silence says a whole lot more than the wrong types of words.

I picked her up and carried her back from her place at the table where we'd shared so many meals, talked and laughed about the trivialities of our days, worked out problems when one of the children had gotten into a jam with another pupil, where we'd celebrated dozens of birthdays, Christmases and anniversaries. You never know when it'll be the last one.

I put the framed wedding photo back on the dresser, touched two fingers to my lips, then to her smiling mouth. Arabella's yearly voyage to the dining room was done.

When I could bring myself to look away, I looked over the paintings on the wall, the faded curtains and tattered cushions, not with the affection that comes with familiarity but with a fresh critical outlook. I got my pad and started making another list, a list of what had to go and what had to be cleaned. I had a new friend coming round next week, and she's bringing radishes.

Second story

People don't seem to notice Betty much in the daytime. But when night falls she glistens blackley, slithers up my arm, crawls across my neck, to perch on my shoulder with her whiskers tickling my earlobe. You know how sometimes a laptop pop-up when you've watched too much of a series in one sitting asks if you're still there? When I feel Betty's saliva pooling on one of my collarbones I know it's time for us both to go to bed. She watches as I brush my teeth, fascinated. I have no qualms undressing before her now, having long ago given up trying to get her to leave my bedroom. She'll only scrape at the door, making me feel guilty.

I'll lie there listening to her softly snoring at the foot of the bed. The rhythm does not send me to sleep; instead I wait in the darkness for her to snuffle and splutter. It's very difficult for me to switch off and not worry about her. She is not in the best of health.

In the days she is quiet, well-behaved. She performs her best trick, getting lost behind me. I walk ahead, wondering if she'll jump out and startle me, knowing all the shortcuts around the blocks as she does. I see other walkers chatting to acquaintances in the park. Betty is yet to make any friends, or help me make friends. She is not menacing, but people either ignore her, or give her a wide berth if she's being playful, straining at the leash I've learned to hold in a very tight grip.

We come back home and I hang her leash on the hook, letting her roam free again. She heads straight to her drinking bowl, nails skittering across the floor. I think how different that sound is to when I'm unable to sleep; an almost insectile clicking. It fights with the ticking of my wall clock for my attention, the sounds magnified in the gloom.

When I first got her she would bark constantly. The slightest thing would wind her up and make her go. No matter how many walls I put between us her yelps would pummel my mind and so I let her sleep on the bed before my grey matter turned completely to dough. The neighbours would reach into their eye bags to shoot me looks of weary irritation the next morning while we set about our business. From my own dark circles I'd send what I hoped were pitiful, placating glances while suppressing a petulant cry of "it's not me – it's her." Or

sometimes I'd go for a tiny apologetic wave that became a tucking of a lock of hair behind my ear when all it succeeded in was making the recipient turn away, focussing all their attention on unlocking their cars or putting out bins. After particularly gruelling nights, I baked the sets of neighbours both sides a batch of bone-shaped cookies, leaving notes in describing how Betty had helped and she was very sorry about all the noise. With a splotch meant to look like she had signed off with a paw print. They ate the cookies and left the containers on my doorstep but never a return note. Never acknowledging the cause of our collective misery.

It's not like I asked for her. She just turned up on the doorstep one day.

As previously mentioned, in the daytime she usually doesn't demand so much attention. But it wasn't always so. Before I trained her, she was a little nightmare. I almost considered renaming her Blasphemy, so often did she have me cussing at some idiotic ruinous thing she had done.

I like to start my weekends by writing in a journal, listings things I'm grateful for. My best friend Suzanne suggested it and, perhaps sensing my reluctance, bought me a pad with 'make every day count' written on it, underlining a picture of a rainbow. I stuck it in a draw. Then one sleepless, nails a-clacking night I started writing in it to grumble about how tired I was and sort of took it from there, really. Betty thinks my writing implements are brightly coloured sticks longing to be gnawed.

After she loses interest in that tug of war, I move on to yoga. Suzanne cannot take credit for that idea. My GP suggested it when I complained of my aching back and cracking joints. When I assume the bridge position, Betty likes to pretend she's at Crufts and I'm an obstacle to either run under or jump over. I gave up doing tree pose after she tried to cock her leg on me.

In the evenings I sometimes like to play on my acoustic guitar. I don't sing very well. Sometimes Betty will howl along. Which had me in hysterics the first few times but then I wondered if she was maliciously trying to drown me out, relegating me to backing singer while she took centre stage.

Occasionally I like to take a bath before bed. I make an event of it – candles, oils, soothing sounds playing from my mobile, a magazine that always ends up damp and curly no matter how careful I try to be. If I'm in there too long, Betty will rest her snout on the bath's rim and gaze at me with those doleful eyes as if wondering why I've decided to become half fish. I see my nakedness reflected in her eyes and find fault with it even in that warped miniature form. I get her to leave by phoning the landline from my mobile.

I tried knitting, as a way to occupy the hands wanting to harm me, to give my scattered thoughts some direction. It works up until the moment Betty decides she’s a cat after all, and bats my balls of wool around the floor.

Me and my shadow. This black dog only I can see, that I’ve had to accept is a part of me. Small enough to fit on my shoulder, pressing down with all the weight of the world

Appendix B

Word lists

Word list

Cat, hat, cow, glass, bowl, candle, door, car, bus, dog, table, rooster, sun, earth, bug, cake, chair, house, dance, soup

Random word list

Fly, mouse, screen, crow, tape, school, mat, rat, cord, lamp, lamb, hound, sofa, kitten, muffin, light, oar, moon, bow, chicken

Appendix C

Questions

Questions about the first story in first session

The protagonist met a woman who was around 5 years younger than him in a grocery store.
True - False

The woman he met works at the grocery store.
True - False

The man was looking for radishes.
True - False

Arabella, his late wife, liked carrots in her salad.
True - False

The woman with the grey eyes scolded her nephew for not keeping the root vegetables stocked.
True - False

The man was looking for specific ingredients because it was his wedding anniversary.
True - False

When the man came home from the grocery store, he heard voices that he recognised.
True - False

The man poured himself a glass of bourbon.
True - False

The man talked to his late wife about his day.
True - False

A new friend was coming to visit the man, and was bringing radishes.
True – False

Answers: False, False, True, False, True, True, Fase, False, True, True

Questions about the second story in first session

The name of the animal in the story was Patty.
True - False

The animal is black in colour.
True - False

The neighbours looked irritated at the protagonist because the animal was barking and howling all night.
True - False

The animal came from the pound.
True - False

The animal is not in the best of health.
True - False

The animal does not make friends easily.
True - False

The protagonist's best friend, Suzanne, suggested that the protagonist do yoga every weekend.
True - False

When the protagonist plays the violin, the animal likes to howl along.
True - False

The animal rests its snout on the edge of the bath.
True - False

The animal represents a physical disability.
True - False

Answers: False, True, True, False, True, True, False, False, True, False

Questions about the first story second session:

First character to speak in the story was a lady with grey eyes.
True - False

The story includes events which take place at a bus stop.
True - False

It was the protagonist's wife's birthday, and he wanted to surprise her with her favourite salad.
True - False

The protagonist was looking for radishes.
True - False

The protagonist's wife was still alive.
True - False

The lady's nephew, Stu, worked at the grocery store.
True - False

When the protagonist came home from the grocery store, there were visitors there.
True - False

The protagonist's wife was watching television while he told her about his day.
True - False

The protagonist made a list of things he needed to change and clean up in his house.
True - False

The protagonist made a new friend.
True - False

Answers: True, False, False, True, False, True, False False, True, True

Question about second story in the second session

The name of the animal in the story was Betty.
True - False

The animal sleeps on her human at night so her whiskers tickles the human's earlobe
True - False

The animal is always well-behaved, and all the neighbours love her.
True - False

The animal has many friends to play with at the park.
True - False

When the protagonist first acquired the animal, she only barked at night.
True - False

The animal enjoys listening to the protagonist playing the piano, and sometimes howls along.
True - False

The protagonist's best friend, Suzanne, suggested it would be good to keep a journal and write in it every day.
True - False

When the protagonist tried to knit, the animal would play with the woollen balls like a cat.
True - False

The protagonist found the animal lost on the streets, and brought her home.
True - False

The animal is used as a metaphor for depression.
True - False

Answers: True, True, False, False, False, False, True, True, False, True.