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EEG Analysis on Brain.fm (Focus)

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Introduction

- 17 subjects were tested to measure effects of a Brain.fm focus session on cognition.
- With 4 additional subjects, we recorded EEG data during baseline and while listening to the Focus session for the different tests and conditions
- 3 cognitive tests were taken in random order:

Reaction Time (RT), Go-No Go (GNG), Visual Pattern Recognition (VPR)

- Reaction time was measured for all 3 tests, and for the last 2 tests the precision (in percentage) was also measured.

The tests were taken under 3 conditions (also randomly assigned):

- Music (tests taken while the subjects were listening to the frequency and amplitude modulated Brain.fm focus session)
- Placebo (tests were taken while the subjects were listening to similar music but without frequency or amplitude modulation)
- No Music

Results

- The results are illustrated in the following slides.
- In all 3 tests the subjects performed statistically significantly better under the Music condition than under Placebo and much better under these conditions than with No Music.
- Averages, standard deviations and the statistical values of the tests are given.
- Parametric tests were performed to determine the statistical significance of the null hypothesis that data in the difference x-y are a random sample from a normal distribution with mean 0 and unknown variance, against the alternative that the mean is not 0. h = 1 indicates a rejection of the null hypothesis at the 5% significance level.

Visual Reaction Time Statistics

Music (mean)	296.4382 ms
Placebo (mean)	306.0659 ms
No Music (mean)	307.6381 ms
Music	44.9236 ms
Placebo	58.1920 ms
No Music	52.7085 ms
Music-Placebo	h1 = 1, p = 0.0441
Music-No Music	h2 =1, p = 0.0023

Graphs

- The results are illustrated in box plots.
- On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually as red marks.
- 2 box plots are provided for the 3 tests and comparison between the condition Music-Placebo and Music-No Music are represented in each box.
- A histogram of the data under the 3 conditions for each test is also given.

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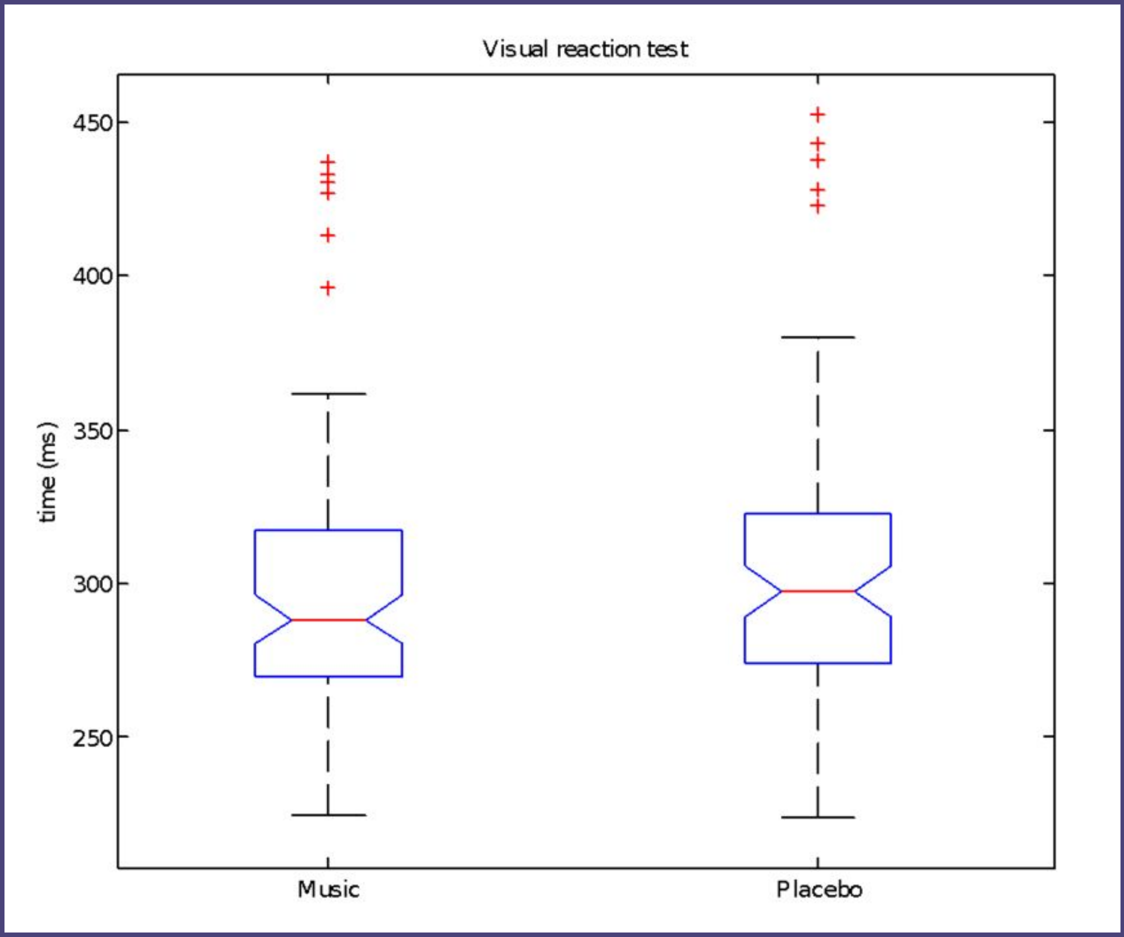

Figure 1: Results for Music vs Placebo for the Reaction Time test.

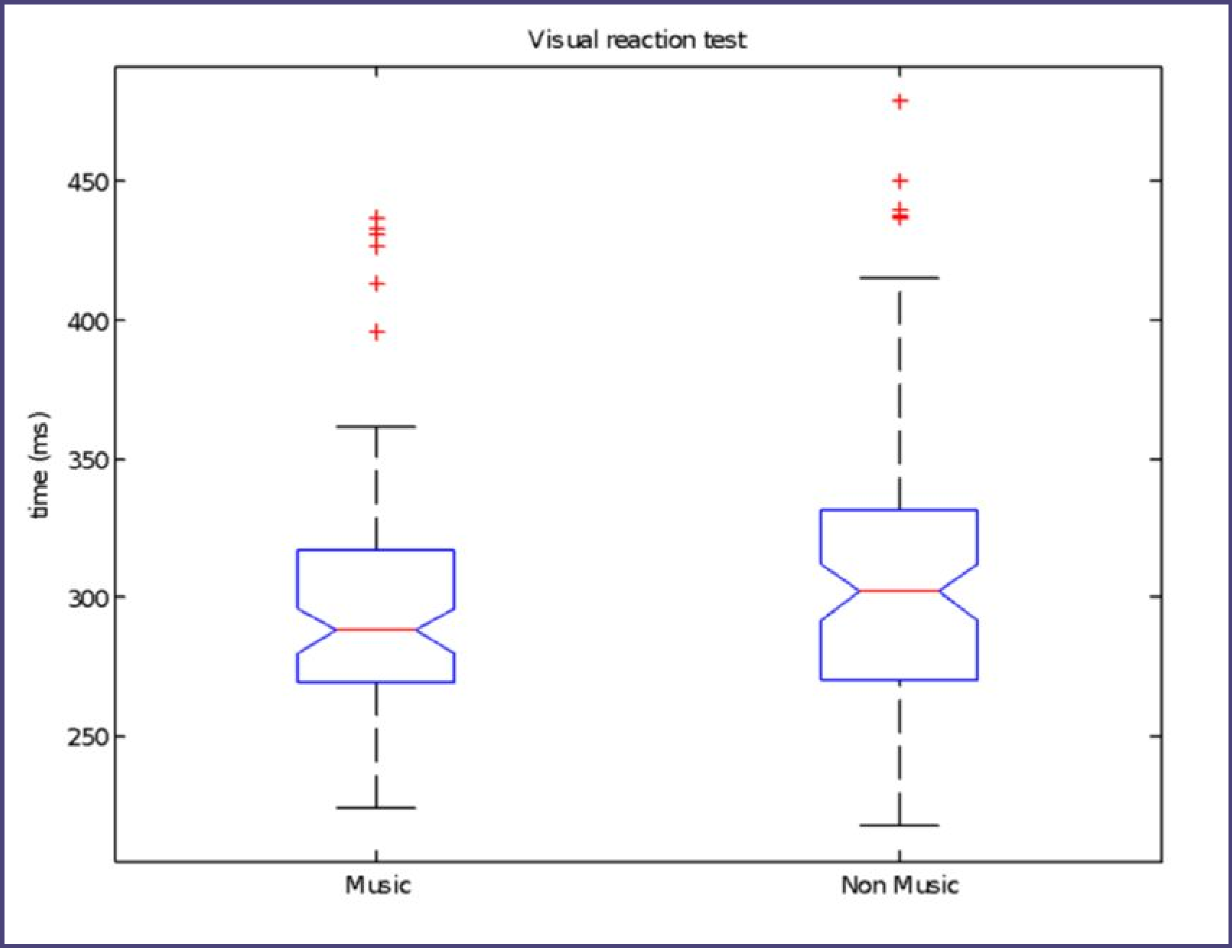

Figure 2: Results for Music vs Non Music for the Reaction Time test.

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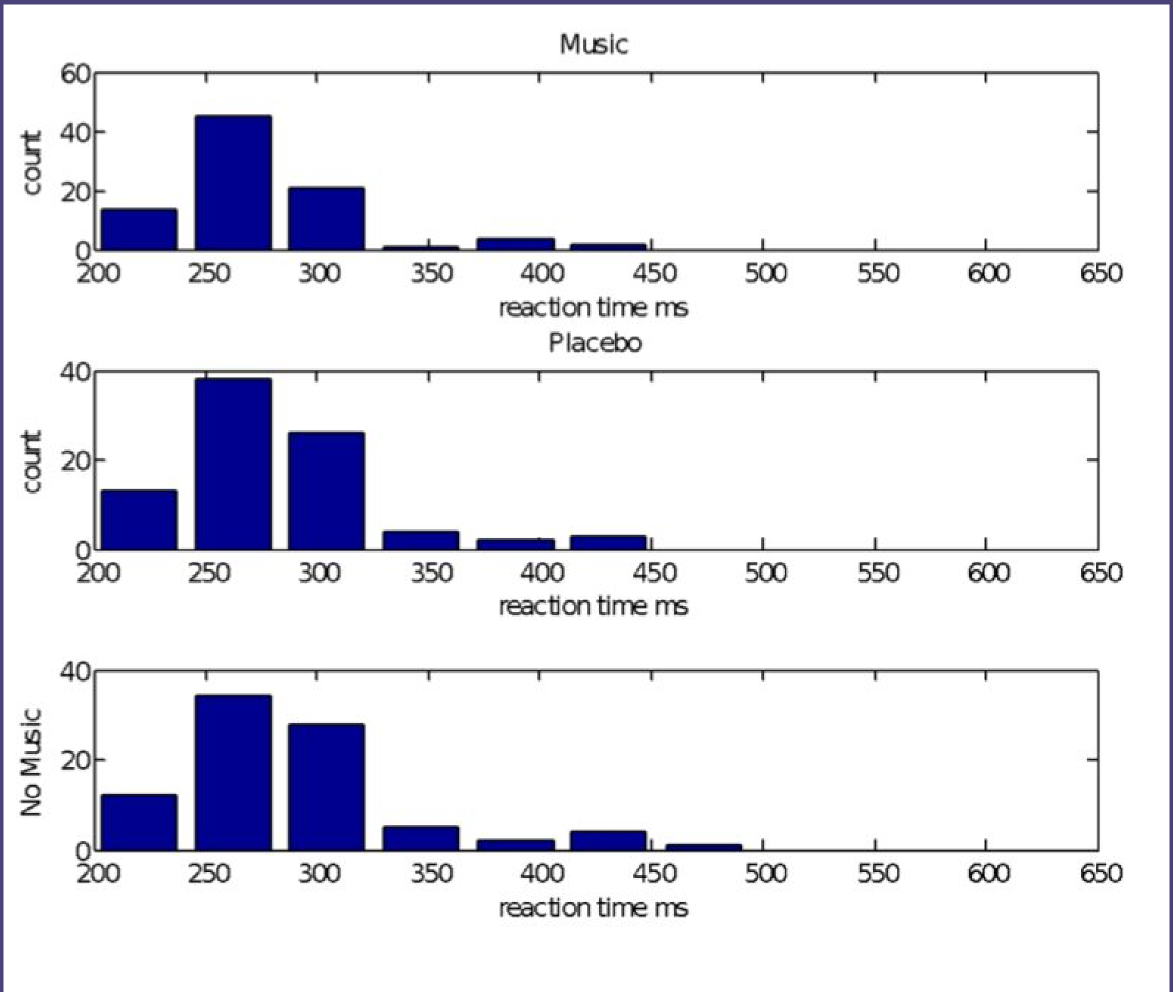

Figure 3: Histogram for the 3 different conditions for the Reaction Time test.

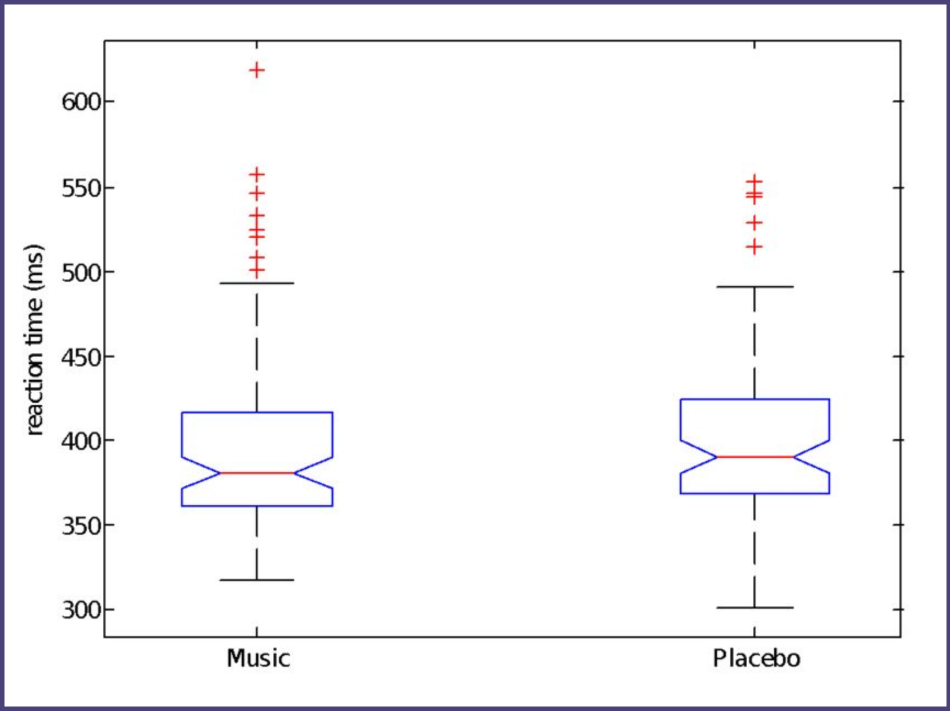

Figure 4: Results for Music vs Placebo for the Go-No Go test.

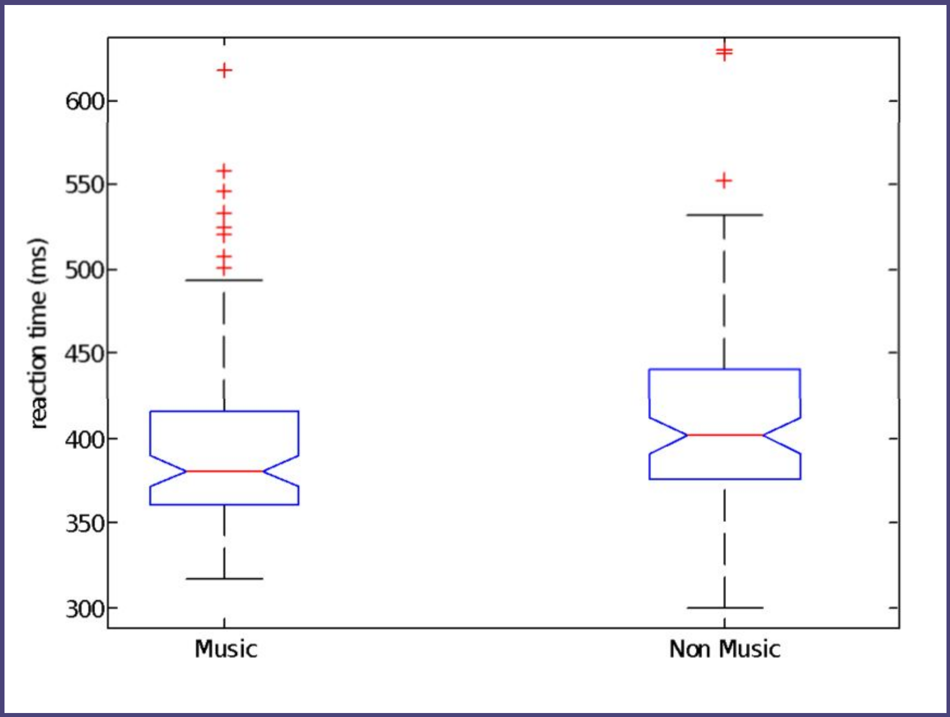

Figure 5: Results for Music vs Non Music for the Go-No Go test.

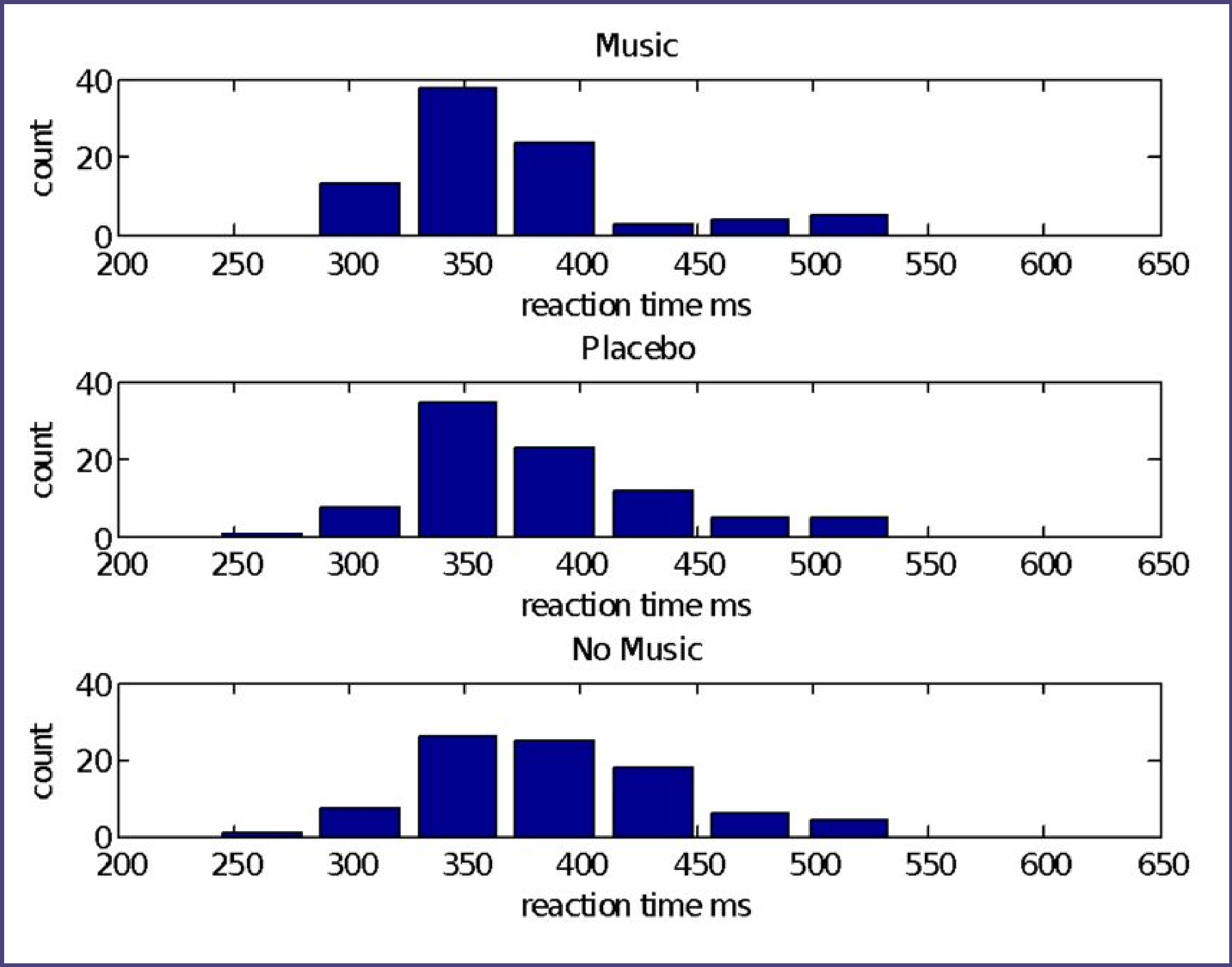

Figure 6: Histogram for the Go-No Go test for the 3 different conditions.

The precision for the 3 Go-No Go conditions was similar at around 92 percent.

The precision changed considerably between conditions for the Pattern Recognition test:

- Music 89 %
- Placebo 86 %
- No Music 83 %

So we calculated a weighted reaction time that is the reaction time times the precision. The value given in the following statistics and graphs are weighted reaction times:

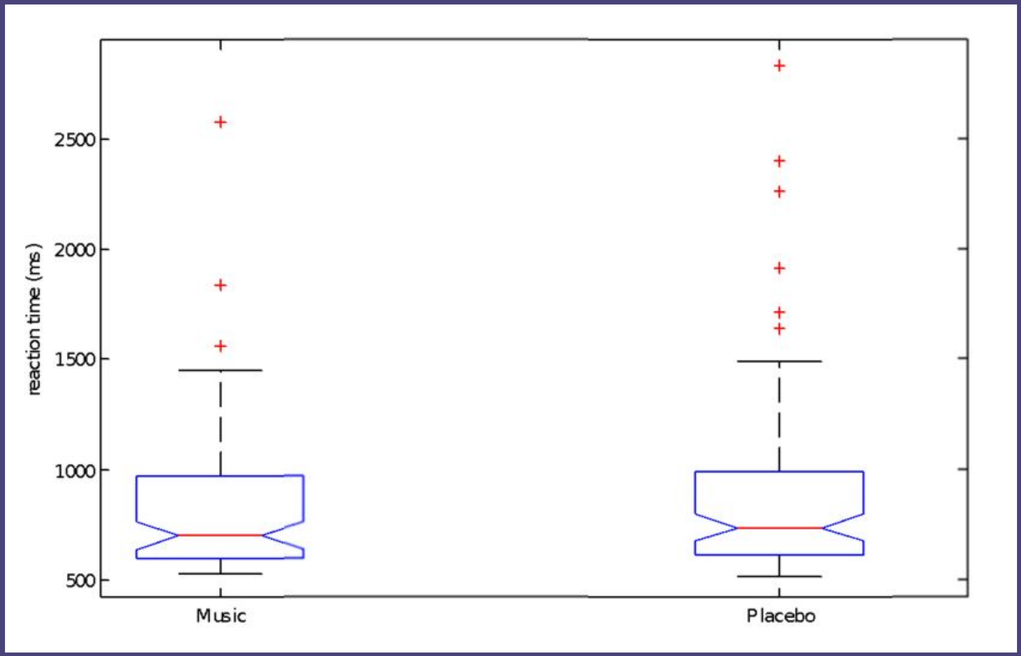

Figure 7: Results for Music vs Placebo for the Pattern Recognition test.

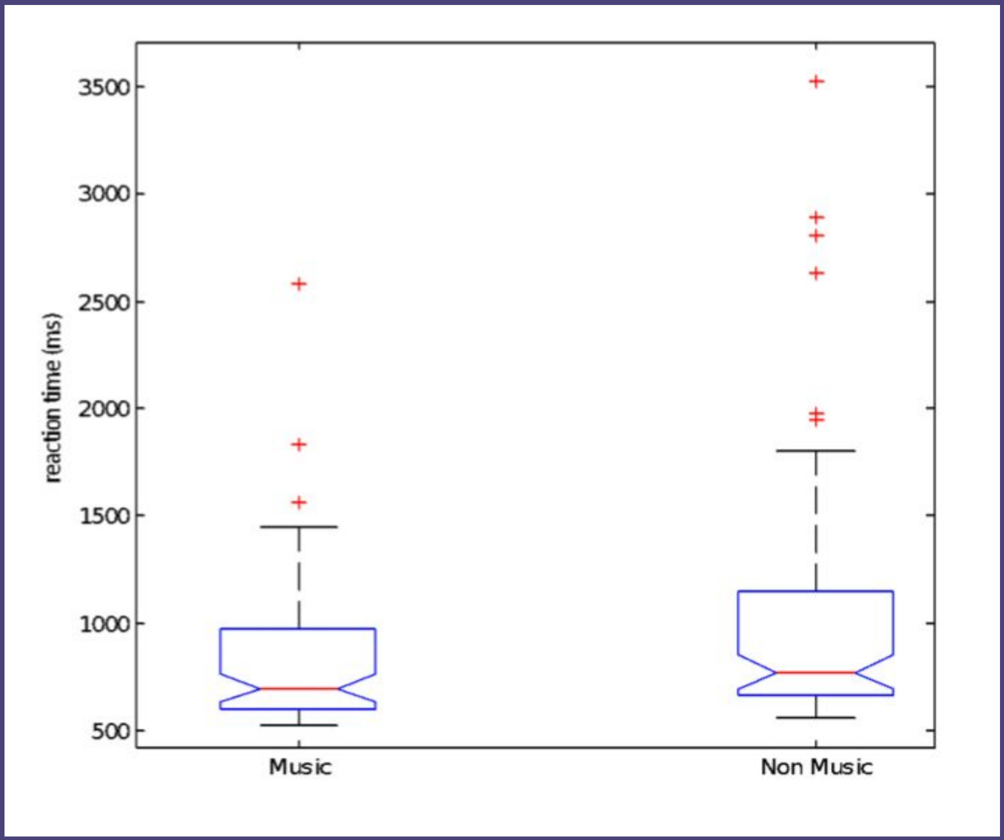

Figure 8: Results for Music vs Non Music for the Pattern Recognition test.

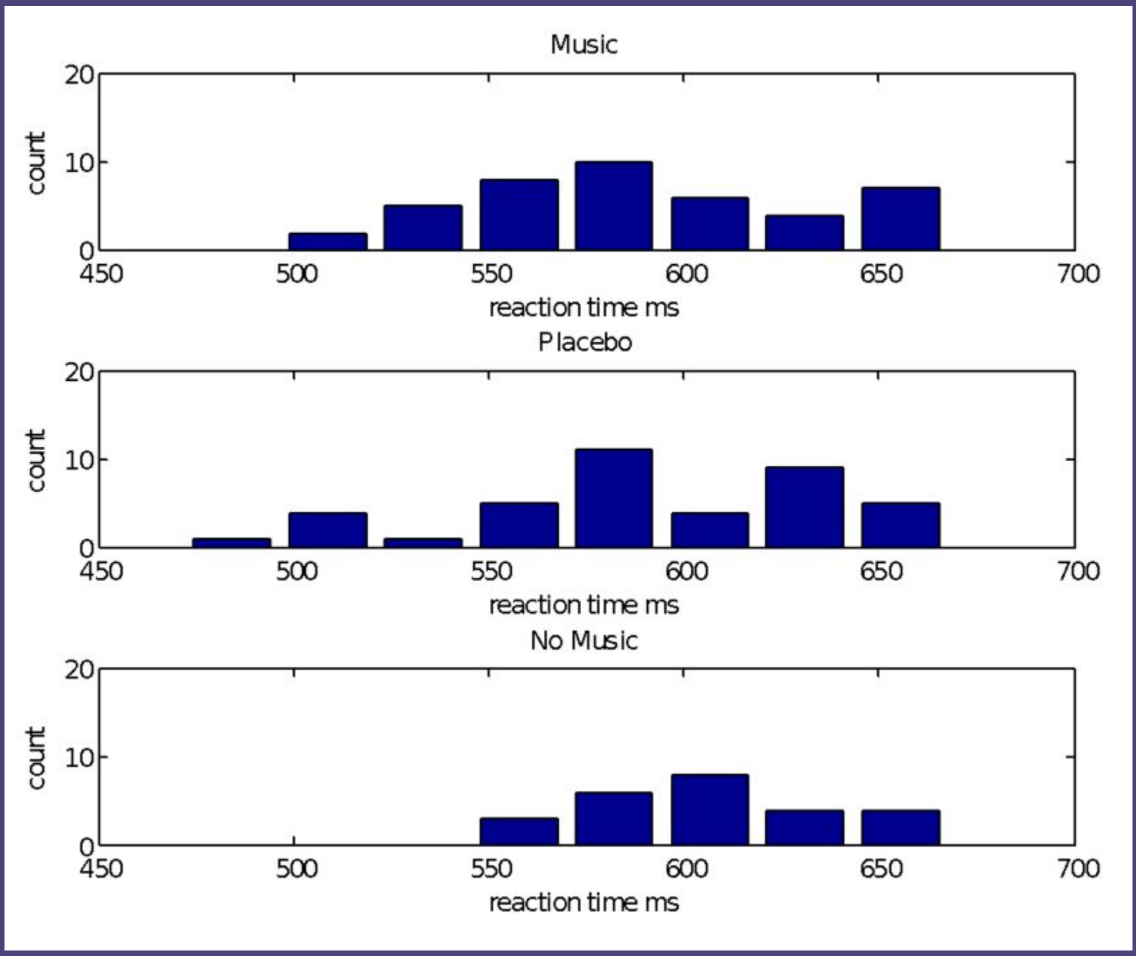

Figure 9: Histogram for the Pattern Recognition test for the 3 different conditions.

Comparison with other Enhancements and Behavioral Tests Results

Snel *et al.* used cognitive tests(Snel, Lorist et al. 1999) to measure the effect of caffeine on focus. In particular the Pattern Recognition test we used for the Brain.fm tests. The study involved 12 subjects and compared performance between two conditions: placebo and 250 mg of caffeine.

The Pattern Recognition test and other behavioral test show no improvement due to caffeine but caffeine did affect the event-related potentials (ERP) in a statistical meaningful way.
We consider the performance of Brain.fm focus session over caffeine given we can observe statistically significant result with just few more subjects than the referenced study.

EEG Results

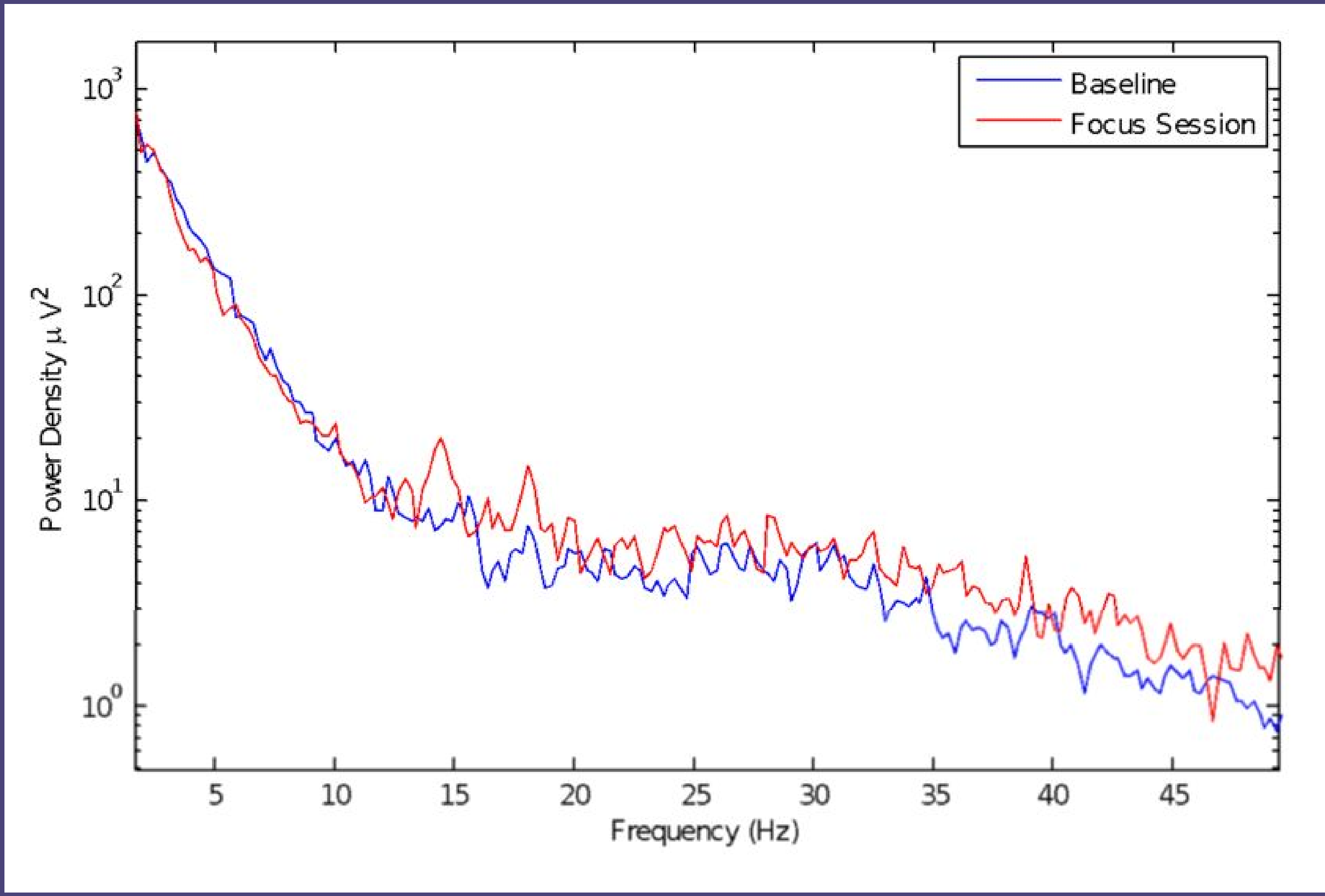

Figure 10: EEG spectrogram for the EEG during baseline vs Focus session. The Focus session is the Reaction Time test. Baseline is test without any music.

We recorded EEG data during baseline and Focus session for the different tests and conditions in 4 subjects (3 males, 1 female).

Figure 10 illustrates results in a Power Spectral Density plot for subject 4 as an example (similar trends are present in the other 3 subjects). The Focus session shows the results of the modulated music on the brain EEG. Prominent spikes in alpha and beta are clearly visible. Overall there is an increase in beta demonstrating more alertness.

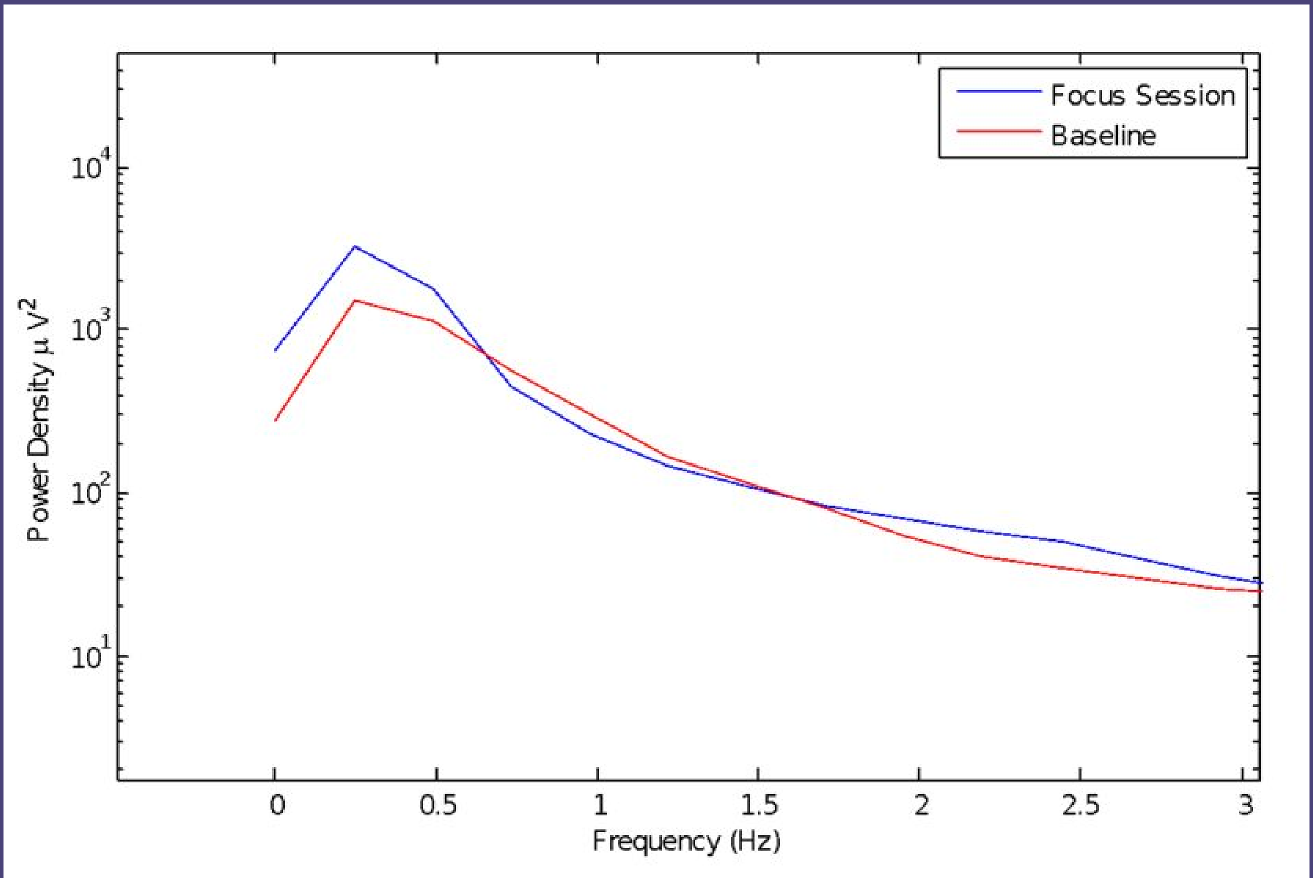

Figure 11: Zoom in in the delta region of Figure 10.

Figure 11 shows a zoom of the EEG for subject 4 in the delta region. There is an increase in delta that has been demonstrated to modulate attention during waking.

EEG Band Power Analysis

We have also measured ratio of the power during the Focus and Baseline conditions for different bands.

Ratio theta over beta

Several studies (Ishigami and Klein 2011) (Fan, Byrne et al. 2007) (Shi, Li et al. 2012) have shown that the ratio theta over beta is a good measure of attention with a decrease in this ratio being correlated with focus.

(less is better)

During Brain.fm focus	10.5946
During Baseline	13.2434

Ratio delta over alpha

Other measures of attention are the ratio delta over alpha (increase is correlated with focus):

(more is better)

During Brain.fm focus	148.4150
During Baseline	126.2951

Ratio gamma over beta

Also an increase of gamma over beta (Gruber, Muller et al. 1999) denotes focus.

(more is better)

During Brain.fm focus	0.8753
During Baseline	0.5345

Mean of the ratio of theta over beta as a function of time

We also calculated the mean of the ratio of theta over beta for all the subjects as a function of time averaging over 10 seconds.

(less is better)

During Brain.fm focus	9.3541
During Baseline	12.3609

We used a two way ANOVA to show statistical significance with the following result:

- hT = 1, pT = 0.0237

Figure 12 illustrates the ratio of theta over beta as a function of time for subject 4.

While during the Focus session this ratio was low and relatively constant (showing a stable focus) during baseline there was an increase of distraction (indicated by the increase in theta over beta) after 120 seconds.

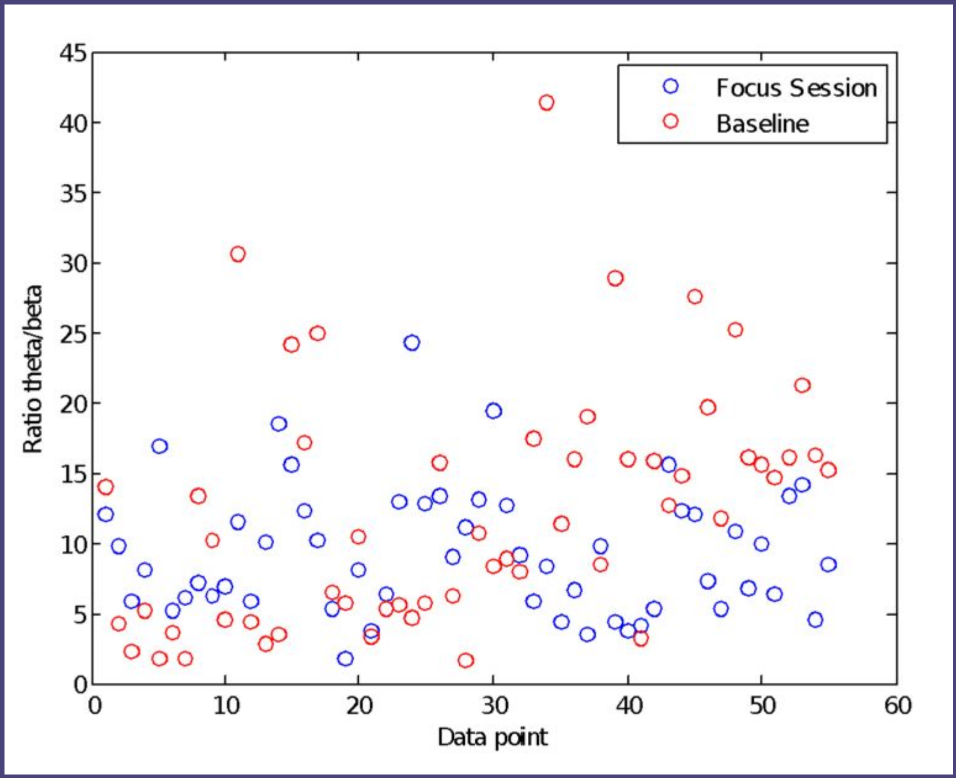

Figure 12: Ratio of theta over beta calculated over intervals of 10 seconds (data points) for subject 4.

References

Fan, J., et al. (2007). "The relation of brain oscillations to attentional networks." Journal of Neuroscience **27**(23): 6197-6206.

Previous studies have suggested the relation of particular frequency bands such as theta (4-8 Hz), alpha (8-14 Hz), beta (14-30 Hz), or gamma (> 30 Hz) to cognitive functions. However, there has been controversy over which bands are specifically related to attention. We used the attention network test to separate three anatomically defined brain networks that carry out the functions of alerting, orienting, and executive control of attention. High-density scalp electrical recording was performed to record synchronous oscillatory activity and power spectrum analyses based on functional magnetic resonance imaging constrained dipole modeling were conducted for each attentional network. We found that each attentional network has a distinct set of oscillations related to its activity. The alerting network showed a specific decrease in theta-, alpha-, and beta-band activity 200-450 ms after a warning signal. The orienting network showed an increase in gamma-band activity at similar to 200 ms after a spatial cue, indicating the location of a target. The executive control network revealed a complex pattern when a target was surrounded with incongruent flankers compared with congruent flankers. There was an early (< 400 ms) increase in gamma-band activity, a later (< 400 ms) decrease in beta-and low gamma-band activity after the target onset, and a decrease of all frequency bands before response followed by an increase after the response. These data demonstrate that attention is not related to any single frequency band but that each network has a distinct oscillatory activity and time course.

Gruber, T., et al. (1999). "Selective visual-spatial attention alters induced gamma band responses in the human EEG." Clinical Neurophysiology **110**(12): 2074-2085.

Objectives: The present study was designed to investigate the attentional modulation of gamma band responses in a visual spatial attention task using a 128-channel-EEG-montage.
Methods: Colored rectangles were presented on a screen. After 500 ms an arrow indicated whether subjects had to shift their attention to the left or right half of the screen to detect target stimuli. During the task, either the attended half of the screen rotated horizontally while the unattended part remained motionless, or vice versa.
Results: When subjects attended the rotating stimulus, we found significantly higher power in a specific gamma band from 35-51 Hz on parieto-occipital electrode sites contralateral to the stimulation side. In addition, after the onset of the arrow which indicated what side subjects should direct their attention to, the 35-51 Hz response shifted from a broad posterior distribution to an increase of power at parietooccipital sites contralateral to the to-be-attended side. Furthermore, the rotating stimulus elicited higher gamma band power as compared to the standing stimulus at electrode locations, which may be related to the activity of underlying cortical structures specialized for motion processing.
Conclusions: The present results replicate important parts of previous findings of enhanced gamma power when a moving stimulus was attended. (C) 1999 Elsevier Science ireland Ltd. All rights reserved.

Ishigami, Y. and R. M. Klein (2011). "Repeated measurement of the components of attention of older adults using the two versions of the Attention Network Test: stability, isolability, robustness, and reliability." Frontiers in Aging Neuroscience **3**.

Ishigami and Klein (2010) showed that scores of the three attention networks (alerting, orienting, and executive control) measured with the two versions of the Attention Network Test (ANT; Fan et al., 2002; Callejas et al., 2005) were robust over 10 sessions of repeated testing even though practice effects were consistently observed especially in the executive network when young adults were tested. The current study replicated their method to examine robustness, stability, reliability, and isolability of the networks scores when older adults were tested with these ANTs. Ten test sessions, each containing two versions of the ANT, were administered to 10 older adults. Participants were asked to indicate the direction of a target arrow, flanked by distractors, presented either above or below the fixation following auditory signals or/and visual cue. Network scores were calculated using orthogonal subtractions of performance in selected conditions. All network scores remained highly significant even after nine previous sessions despite some practice effects in the executive and the alerting networks. Some lack of independence among the networks was found. The relatively poor reliability of network scores with one session of data rises to respectable levels as more data is added.

Shi, T. K., et al. (2012). "EEG characteristics and visual cognitive function of children with attention deficit hyperactivity disorder (ADHD)." Brain & Development **34**(10): 806-811.

Using visual and auditory continuous performance tests (CPT) and EEG, cognitive function and EEG power were investigated in patients with attention deficit hyperactivity disorder (ADHD). CPT and EEG were conducted for 44 ADHD children and 44 healthy controls of comparable age and sex. The EEG power tests include relative power of theta, alpha, and beta, and theta/beta and theta/alpha ratios. ADHD patients showed significantly higher theta relative power, lower beta relative power, and higher theta/beta ratio ($p < 0.05$). ADHD patients showed a significantly lower score of auditory CPT ($p < 0.05$). The EEG power characteristics were correlated significantly with the visual attention function in ADHD children ($p < 0.01$). Higher-order level cognitive dysfunction affects ADHD pathogenesis. Cortical hypoarousal effects on several mechanisms including the fronto-striatal circuitry may be implicated in the inhibition of prepotent and premature responses. (C) 2012 The Japanese Society of Child Neurology. Published by Elsevier B.V. All rights reserved.

Snel, J., et al. (1999). "Effects of caffeine on attention." 18th International Scientific Colloquium on Coffee: 208-209.