UNIVERSITY NAME (IN BLOCK CAPITALS)

Thesis Title

by

Author Name

A thesis submitted in partial fulfillment for the
degree of Doctor of Philosophy

in the
Faculty Name
Department or School Name

August 2015

Declaration of Authorship

I, AUTHOR NAME, declare that this thesis titled, 'THESIS TITLE' and the work presented in it are my own. I confirm that:

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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"Write a funny quote here."

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UNIVERSITY NAME (IN BLOCK CAPITALS)

Abstract

Faculty Name
Department or School Name

Doctor of Philosophy

by Author Name

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too...

Acknowledgements

The acknowledgements and the people to thank go here, don't forget to include your project advisor…

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For/Dedicated to/To my…

Introduction

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Methods

Participants

Fourteen participants (3 male), aged 19-36, with normal hearing and no history of brain injury took part in this study. Eight participants had formal musical training (1- 26 years), and four of the participants played instruments regularly at the time of data collection.

TABLE 1: Information about the tempo, meter and length of the stimuli used in this experiment.

ID	Name	Meter	Length	Tempo	#Bars	Bar Length
1	Chim Chim Cheree (lyrics)	3/4	13.3s	212 BPM	16	0.85s
2	Take Me Out to the Ballgame (lyrics)	3/4	7.7s	189 BPM	8	0.95s
3	Jingle Bells (lyrics)	4/4	9.7s	200 BPM	8	1.20s
4	Mary Had a Little Lamb (lyrics)	4/4	11.6s	160 BPM	8	1.50s
11	Chim Chim Cheree	3/4	13.5s	212 BPM	16	0.85s
12	Take Me Out to the Ballgame	3/4	7.7s	189 BPM	8	0.95s
13	Jingle Bells	4/4	9.0s	200 BPM	8	1.20s
14	Mary Had a Little Lamb	4/4	12.2s	160 BPM	8	1.50s
21	Emperor Waltz	3/4	8.3s	178 BPM	8	1.01s
22	Hedwig's Theme (Harry Potter)	3/4	16.0s	166 BPM	15	1.08s
23	Imperial March (Star Wars Theme)	4/4	9.2s	104 BPM	4	2.30s
24	Eine Kleine Nachtmusik	4/4	6.9s	140 BPM	4	1.71s

Stimuli

Stimuli were fragments of familiar musical pieces and were selected based on key signature (3/4 or 4/4 time) and the presence and absence of lyrics. The stimuli were kept as similar in length as possible with care taken to ensure that they all contained complete musical phrases. Stimulus details can be found in Table 1. Each musical fragment was preceded by approximately two seconds of clicks as a cue to the tempo and onset of the music. The beats began to fade out at the one second mark and stopped at the onset of the music.

Equipment and Procedure

Behavioural Testing

We collected information about the participants' previous music experience, their ability to imagine sounds, and information about musical sophistication using an adapted version of the widely used Goldsmith's Musical Sophistication Index (G-MSI) [**?**] combined with an adapted clarity of auditory imagination scale [**?**]. We also had participants complete a beat tapping and a stimuli familiarity task. Participants listened to each stimulus and were asked to tap along with the music on the table top. The experimenter then rated their tapping ability on a scale from 1 (difficult to assess) to 3 (tapping done properly). After listening to each stimulus participants rated their familiarity with the stimuli on a scale from 1 (unfamiliar) to 3 (very familiar). To participate in the electroencephalography (EEG) portion of the study, the participants had to receive a score of at least 90% on our beat tapping task. Participants received scores from 75%–100% with an average score of 96%. Furthermore, they needed to receive a score of at least 80% on our stimuli familiarity task. Participants received scores from 71%–100% with

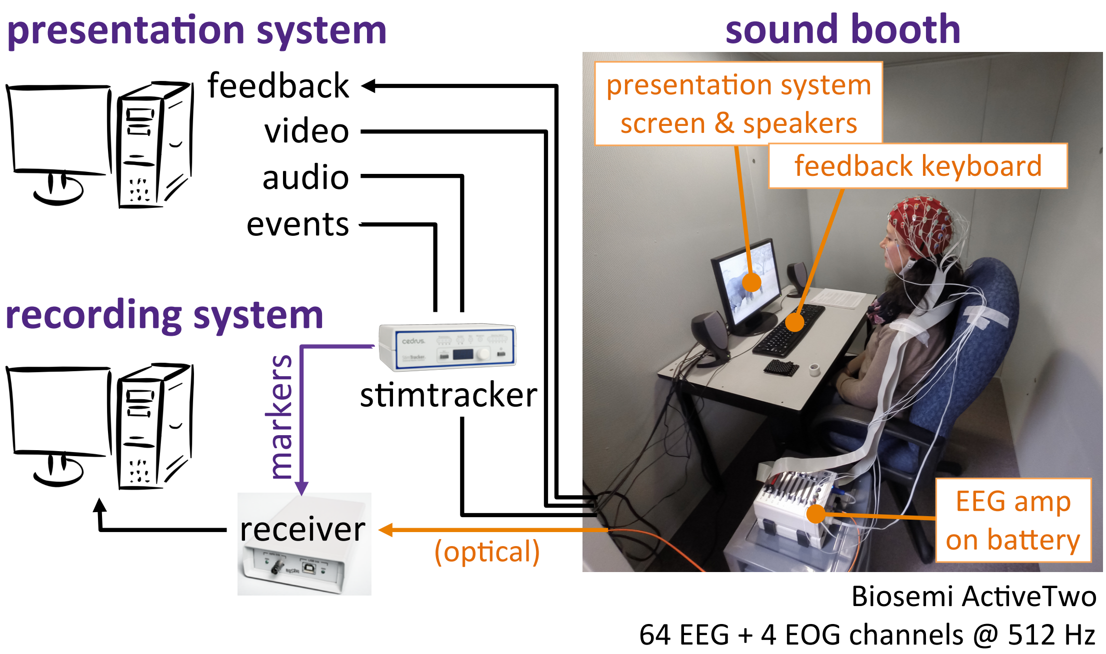

FIGURE 1: Setup for the EEG experiment. The presentation and recording systems were placed outside to reduce the impact of electrical line noise that could be picked up by the EEG amplifier.

an average score 87%. These requirements resulted in rejecting 4 participants. This left 10 participants (3 male), aged 19–36, with normal hearing and no history of brain injury. These 10 participants had an average tapping score of 98% and an average familiarity score of 92%. Eight participants had formal musical training (1–10 years), and four of those participants played instruments regularly at the time of data collection.

EEG recording

For the EEG portion of the study, the 10 participants were seated in an audiometric room (Eckel model CL-13) and connected to a BioSemi Active-Two system recording 64+2 EEG channels at 512 Hz as shown in Figure 1. Horizontal and vertical EOG channels were used to record eye movements. We also recorded the left and right mastoid channel as EEG reference signals. Due to an oversight, the mastoid data was not collected for the first 5 subjects. The presented audio was routed through a Cedrus StimTracker connected to the EEG receiver, which allowed a high-precision synchronization (<0.05 ms) of the stimulus onsets with the EEG data. The experiment was programmed and presented using PsychToolbox run in Matlab 2014a. A computer monitor displayed the instructions and fixation cross for the participants to focus on during the trials to reduce eye movements. The stimuli and cue clicks were played through speakers at a comfortable volume that was kept constant across participants. Headphones were not

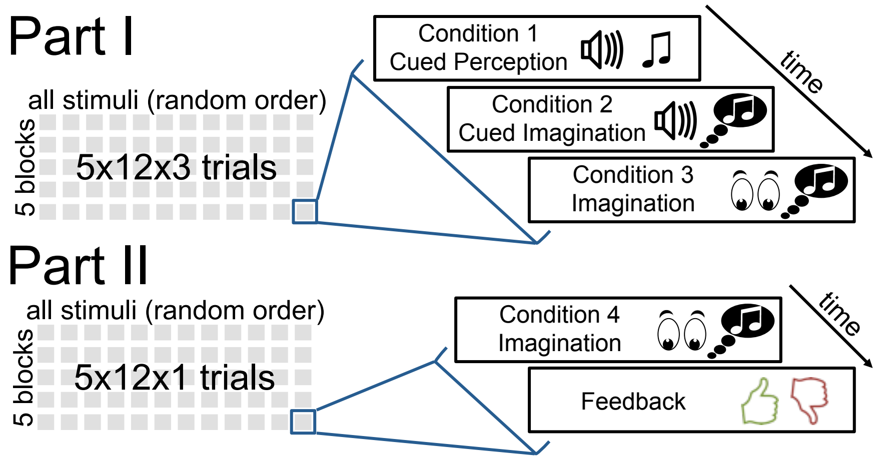

FIGURE 2: Illustration of the design for the EEG portion of the study.

used because pilot participants reported headphones caused them to hear their heartbeat which interfered with the imagination portion of the experiment. After the experiment, we asked participants the method they used to imagine music. The participants were split evenly between imagining themselves producing the music (singing or humming) and simply "hearing the music in [their] head."

The EEG experiment was divided into 2 parts with 5 blocks each as illustrated in Figure 2.

A single block comprised of all 12 stimuli in randomized order. Between blocks, participants could take breaks at their own pace. We recorded EEG in 4 conditions:

1. Stimulus perception preceded by cue clicks
2. Stimulus imagination preceded by cue clicks
3. Stimulus imagination without cue clicks
4. Stimulus imagination without cue clicks, with feedback

The goal was to use the cue to align trials of the same stimulus collected under conditions 1 and 2. Lining up the trials allows us to directly compare the perception and imagination of music and to identify overlapping features in the data. Conditions 3 and 4 simulate a more realistic query scenario during which the system does not have prior information about the tempo and meter of the imagined stimulus. These two conditions were identical except for the trial context. While the condition 1–3 trials were recorded directly back-to-back within the first part of the experiment, all condition 4 trials were recorded separately in the second part, without any cue clicks or tempo priming by prior presentation of the stimulus. After each condition 4 trial, participants provided feedback by pressing one of two buttons indicating on whether or not they felt they had imagined the stimulus correctly. In total, 240 trials (12 stimuli x 4 conditions x 5 blocks) were recorded per subject. The event markers recorded in the raw EEG comprise:

- Trial labels (as a concatenation of stimulus ID and condition) at the beginning of each trial
- Exact audio onsets for the first cue click of each trial in conditions 1 and 2 (detected by the Stimtracker)
- Subject feedback for the condition 4 trials (separate event IDs for positive and negative feedback)

Preprocessing

The raw EEG and EOG data were processed using the MNE-Python toolbox. For recordings with additional mastoid channels, the EEG data was re-referenced by subtracting the mean mastoid signal [**?**]. We then removed and interpolated bad EEG channels identified by manual visual inspection. For interpolation, the spherical splines method described in [**?**] was applied. The data were then filtered with an fft-bandpass, keeping a frequency range between 0.5 and 30 Hz. This also removed any slow signal drift in the EEG. Afterwards, we down-sampled to a sampling rate of 64 Hz. To remove artifacts caused by eye blinks, we computed independent components using extended Infomax independent component analysis (ICA) [**?**] and semi-automatically removed components that had a high correlation with the EOG channels. Finally, the 64 EEG channels were reconstructed from the remaining independent components without reducing dimensionality.

Results

ERP Analysis

Schaefer et al. [**?**] used very short stimuli (3.26s) allowing each stimulus to be repeated many times during during the experiment. This allowed them to average across hundreds of short trials. They then concatenated the grand average ERPs and applied a principle component analysis (PCA), which resulted in clearly defined spatial features. The time courses of these spatial features allowed for classification of their stimuli. We started by trying to replicate these results. We had fewer repetitions of our stimuli. Therefore, to preserve as much data as possible we used the full length of the trials as opposed to

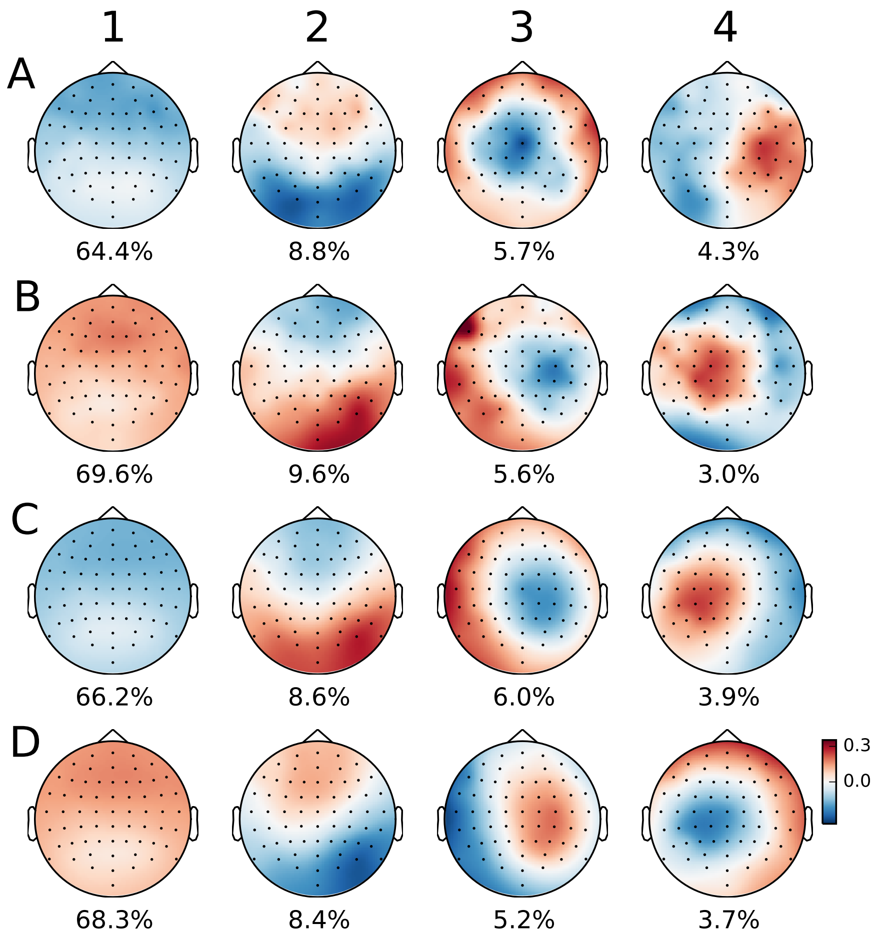

FIGURE 3: Topographic visualization of the top 4 principle components with percentage of the explained signal variance. Channel positions in the 64-channel EEG layout are shown as dots. Colors are interpolated based on the channel weights. The PCA was computed on **A**: the grand average ERPs of all perception trials, **B**: the grand average ERPs of all cued imagination trials, **C**: the concatenated perception trials, **D**: the concatenated cued imagination trials.

the first 3.26 seconds. We computed grand average ERPss by aggregating over the full length of all trials (excluding the cue) of the same stimulus from all subjects. We then concatenated the grand average ERPs and applied a PCA. This resulted in principle components with poorly defined spatial components Figure 3 (A and B).

In order to preserve even more of the data and we took an alternative approach and performed a PCA on the concatenated raw trials without first calculating an average across trials. This produced clearly defined spatial components Figure 3 (C and D). Except for their (arbitrary) polarity the components are very similar across the two conditions, which replicates the results found in [**?**].

Component Waveform Correlations

To show how similar. Component waveforms ? correlation between perception and imagination

Classification

Schaefer et al. [**?**] were able to use the unique time course of the component responsible for the most variance to differentiate between stimuli. Analyzing our components we have not yet been able to reproduce this significant stimulus classification accuracy. This could be caused by our much smaller number of trials which are substantially longer than those used by [**?**]. do we have numbers we can show here?

Different classification approach ? convolutional auto encoder (CAE) to produce components. What are the parameters? Fed waveforms of these components to convolutional neural network (CNN). What are the parameters here? 2 experiments ? 12 class and 2 class

Appendix A

An Appendix

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