Reading with and without Background Music: An Exploration with EEG, Eye Movement and Heart Rate

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ABSTRACT: The effects of background music on learning have been studied in related fields, including psychology and education, but findings are mostly inconclusive. In addition to measurements at the behavioural level, multimodal physiological signals can provide new evidence for exploring the question. This paper presents a pilot study of a reading task for a group of university students whose electroencephalogram (EEG) signals, eye movements, and heart rates were recorded with and without background music. Preliminary results demonstrated the feasibility of integrating multimodal learning analytics to probe the underlying mechanism about the effects of background music on learning.

Keywords: Background Music, Reading Comprehension, EEG Signals, Eye-tracking, Heart Rate

1 INTRODUCTION

Music is a widely-employed stimulus in daily life that elicits entertainment, aesthetic, or spiritual experiences, and/or provides background for other activities such as learning and working. Nonetheless, with regard to the effects of background music on learning, there are many conflicting and inconsistent results. In an recent systematic review (de la Mora Velasco & Hirumi, 2020), some studies have found that background music facilitates memory and recall of information, improves concentration on academic tasks, and enhances mood and emotional states; however, others have reported neutral or negative effects. Two hypotheses, namely arousal-mood-hypothesis and irrelevant-sound-effect, are proposed to explain the mixed results, with focuses on the perspective of emotion or cognition respectively (Li et al., 2020).

Results of existing studies mostly include behavioural measurements such as academic performance and self-reported engagement level, whereas it is known that physiological signals are indicators of cognitive and affective activities (Hu et al., 2019). For instance, electroencephalogram (EEG) signals can reflect the fluctuation of emotional status (Suhaimi et al., 2020). Heart rate variability is deemed as an indicator of cognitive load (Cowley et al., 2013). In terms of eye movements, longer fixation durations and more regressions tend to indicate that the ongoing process of reading is cognitively demanding (Johansson et al., 2012). However, little research has attempted to explore the effects of music on reading with multimodal data input at both behavioural and physiological levels (Hu et al., 2019). New empirical evidence is thus needed to probe the effects of background music on learning and for potentially designing methods that can facilitate the selection of suitable study music.

Recent advancement in learning analytics has begun to examine the cognitive and affective effects of music on learning, such as mental workload and emotional states of students (Hu et al., 2019; Li et al., 2020). This paper presents a pilot user experiment which investigates how background music affects cognitive load and arousal level of students based on analytics of multimodal physiological signals. In particular, this study focuses on reading comprehension, one of the most common learning tasks, with two audio conditions (i.e., background of self-preferred music and silence). In this experiment, participants' interaction logs and multimodal data, including EEG signals, eye movements and heart rates, were recorded simultaneously. Physiological metrics were analysed and compared across audio conditions, revealing interesting results worthy of further exploration.

2 METHODS

2.1 Participants

The pilot study recruited 14 undergraduate students (7 males, 7 females) from a diversified range of majors (e.g. cognitive science, computer science, and bioengineering) in a comprehensive university in the U. S. The mean age of the participants was 22 (SD = 3.0). Five of them reported English as mother tongue. None of them reported visual, hearing or learning impairment.

2.2 Reading Task

Learners acquire knowledge through reading in both physical and digital spaces. In this experiment, participants read eight passages on a computer screen. The passages were selected from GRE-level reading samples, which are generally considered challenging. They covered different topics such as astronomy, geography, history. The experiment contained two blocks, each with two control and two experimental trials. In each trial, participants were tasked to read a passage and answer two questions about its content. The four experimental trials played distinct music pieces in the background from the participants' own choices. In contrast, participants read in silence in the control trials.

2.3 Experimental Apparatus

State-of-art wearable devices were employed to collect multimodal signals. Pupil Core recorded eye movements during reading with sampling rates of 200 Hz in the eye camera and 30 Hz in the world camera. A research-grade wristband, Empatica E4, recorded peripheral physiological signals, including heart rate (HR, 1 Hz), Electrodermal Activity (EDA, 4 Hz), Blood Volume Pulse (BVP, 64 Hz), Skin Temperature (TEMP, 4 Hz). EEG signals were recorded with a 5-channel Cognionics Wireless headset that included electrode sites Cz, Fp1, Fp2, O1 and O2 with a sampling rate of 2000Hz. All of the apparatus could collect data from participants in both physical and digital space. All recorded data were synchronized by timestamps and anonymized to maintain confidentiality.

2.4 Data Analysis

Figure 1 shows the data processing pipeline. Incomplete and invalid data were removed. For each reading period, we removed the first 8 seconds of EEG and heart rate signals, because the data of the first few seconds were likely to be affected by previous activities (Liesefeld, 2018). All of the multimodal signals were segmented on the basis of the start and end time of the reading period corresponding to each passage. Features were further derived from the signal segments according to the corresponding feature extraction methods. After that, we averaged the features in the same audio condition across passages. Finally, paired features were compared between the two audio conditions.

EEG signals were recorded using Lab Streaming Layer (LSL), a middleware for synchronizing signals from multiple sources. High-frequency bands such as alpha, beta and gamma have been taken as effective measures to classify emotions in both valence and arousal dimensions (Suhaimi et al., 2020). Thereby, we used EEGLAB to extract bands of alpha (8-13Hz), beta (13-30Hz) and gamma (30-80Hz). In particular, we computed the mean log spectrum power from the central channel location (i.e., 'Cz').

Eye movements were recorded both through LSL and Pupil Core eye tracker. This paper focuses on eye fixations features which were extracted with Pupil Player, the analytic software coming with Pupil Core. Fixation detection is based on a dispersion-duration method, based on which three measures were calculated. (a) Fixation Number: aggregated fixation counts of each passage. (b) Fixation Duration: aggregated fixation duration of each passage. (c) Mean Fixation Duration: average duration of each fixation.

Heart rates (HR) were recorded using Empatica E4 wristband. Descriptive statistics were extracted from heart rates, including: (a) Mean, (b) Standard deviation (SD), (c) Range.

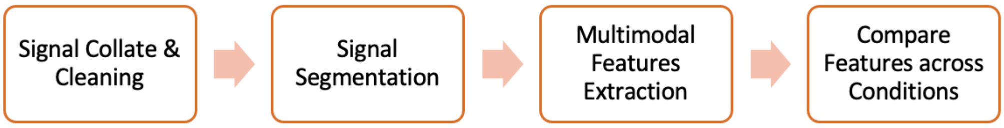
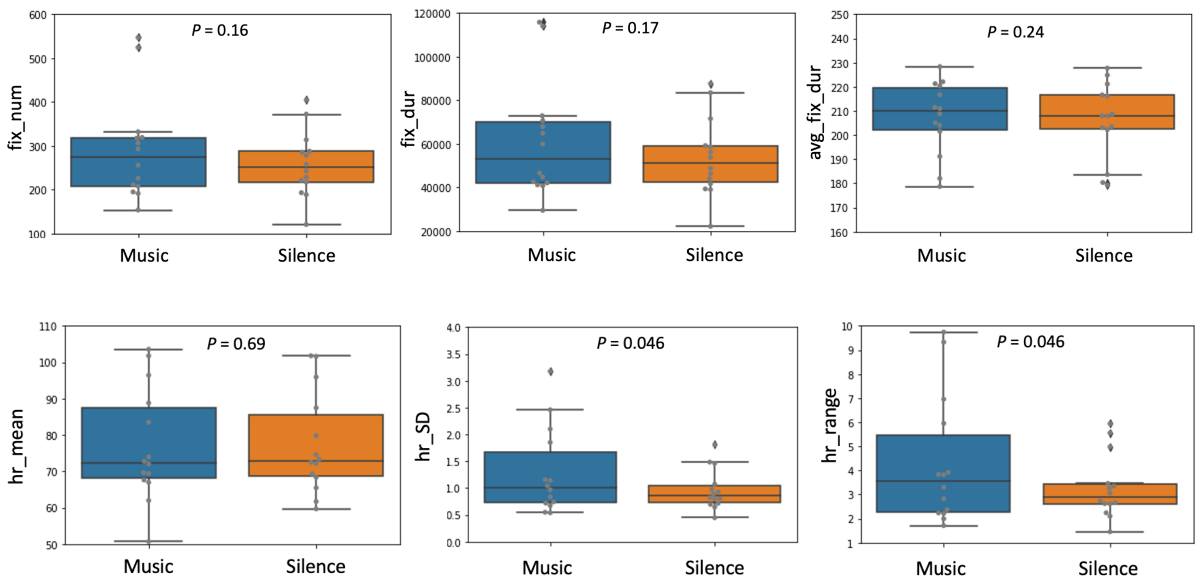


Figure 1. Data Processing Pipeline

3 PRELIMINARY RESULTS

To compare the difference between audio conditions, we first used boxplots to visualize the results from 14 participants (7 males, 7 females) for whom we recorded multimodal signals in terms of eye fixations, HR, and EEG spectra for each audio condition (Figure 2-1, 2-2, 2-3). After that, we applied Paired-sample T-tests to calculate the significant levels of the differences. Preliminary results found significant differences in HR standard deviation and range at p = 0.05 level. No significant differences were detected in measures of HR mean, eye fixation number and duration, average eye fixation duration, or EEG spectra measures at p = 0.05 level.



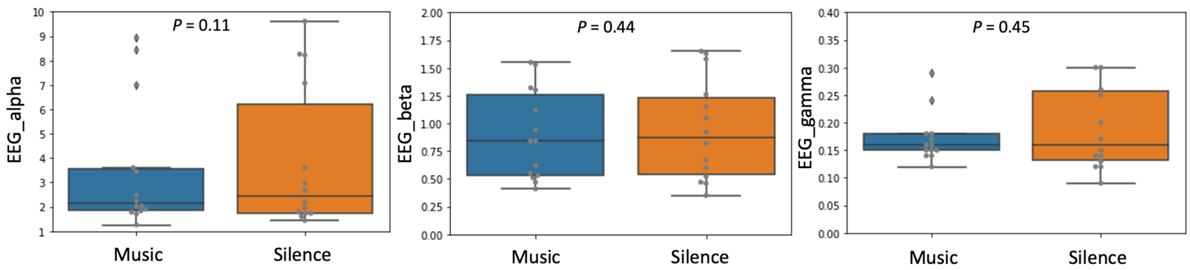


Figure 2-1, 2-2, 2-3. Eye-tracking, HR, EEG Features

4 CONCLUSIONS AND FUTURE WORK

In this study, we reported preliminary results of a within-subject experiment that was conducted with two background audio conditions (i.e., music vs. silence) while participants were engaged in reading comprehension tasks in the digital space. It demonstrated the feasibility of investigating music and learning through a multimodal learning analytics perspective, particularly the mechanisms of collecting multimodal physiological data simultaneously. In the future, we will recruit more participants, analyse fine-grained characteristics of background music selected by the individuals, and interpret the results of multimodal physiological signals from emotional and cognitive perspectives.

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