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Should Improvisation Be Regularly Included in Music Lessons? A Single-Case Quasi-Experimental Study Exploring the Differences in the Electrical Activity of the Brain between Musical Improvisation and Sight-Reading

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Abstract: Thanks to advances in portable electroencephalography technology (PEEGT), investigating the states of the mind is a relatively new area of research with a promising future in music education. Our aim, drawing upon PEEGT, was to contribute to the study of the differences in brain activity between piano music improvisation and sight-reading. We used the EMOTIV Insight helmet to register brain activity in repeated instances of one purposefully selected case while pursuing these two activities in experimental, controlled conditions. Thereafter, we pursued descriptive and robust statistical analysis of the variables offered by the Emotiv software. The quantitative data resulting from our study were triangulated with the qualitative analysis of a logbook filled by the participant on his subjective experiences. While the quantitative results were not statistically significant in measuring differences between the experimental conditions, trends were indeed found in the data and triangulated by our qualitative results. Our study provides preliminary evidence that supports the value of regularly incorporating musical improvisation moments in music education. This, to increase the students' excitement towards music lessons in cases that are similar to the case under scrutiny. Finally, implications and limitations are discussed in relation to the research design, the use of PEEGT technology, and the Emotiv software and hardware for investigating brain activity in pursuing musical activities.

Keywords: music; brain; education; EEG; Emotiv

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1. Introduction

In the human brain, there are an estimated 100 trillion connections between nerve cells, a number that is at least 1000 times the number of stars in our galaxy [1]. As if that were not enough, the number of theoretically possible connections between neurons is more than the number of atoms in the universe [2]. In other words, the brain is of an extraordinary complexity, and the understanding of its functioning is still in its infancy [3]. However, comprehension of brain functioning in relation to music might be of crucial relevance for music education. Indeed, Hodges [4] hypothesises three stages for the evolution of music education based on advances in neuroscience. In the first stage, the study of different practices and methods based on trial and error would be the objective of neuroscience in music education. The second stage would occur when neuroscience is able to support best practices in music education. Finally, Hodges [4] speculates about a third stage in which the knowledge of the brain increases exponentially, and neuroscience might thus streamline teaching through the discovery of innovative methods that would be difficult or impossible to devise otherwise. Hodges' theorisation [4] serves as a rationale for why the studies of brain functioning may be relevant for music education, even if the majority of such studies may still be placed in the first or, at most, the second of Hodges' stages in the present moment.

There are different methodologies for researching the brain, such as electroencephalography (EEG) and magnetic resonance imaging (MRI), or its variant, functional magnetic resonance imaging (fMRI). These different methodologies each have advantages and disadvantages. In the case of EEG, the measurements are carried out on the electrical activity in the cerebral cortex by, for example, portable electroencephalography technology (PEEGT). These electrical signals are usually interpreted in terms of the operation of groups made up of several thousand neurons that create a synchronised electrical activity by being activated simultaneously. The electrical activity found in this way is, in turn, correlated with different states of the mind [5]. EEG has the advantage of a high temporal resolution, i.e., a large amount of data per time unit, although the measurements solely derive from the electrical activity registered in the cerebral cortex. In the case of MRI, the situation is the opposite; MRI is a method that provides an image of the anatomical structure of the brain. However, it does not gather information about the activity in the brain. In contrast, fMRI is a method that can indeed provide information about both the activity in the brain and where it occurs by measuring the blood flow through the brain. The temporal resolution is nevertheless significantly lower than with the data obtained by EEG. Which method is best, therefore, depends on what is to be investigated and whether spatial or temporal data is more relevantly considered [6]. In the case of the present study, EEG was the selected method based on our intentions to prioritise the latter. Furthermore, this method has been used extensively for measuring responses to stimuli [3].

The aim of the present study is to undertake a quasi-experimental single-case study to investigate how one's state of mind is comparatively affected by the selected participant's performance in two common musical activities at the piano: musical improvisation (i.e., freely creating music in real-time) and sight-reading (i.e., playing a music score by real-time reading, without prior study of the score). The results may add to an area that is still in much need of research regarding the possibilities that modern technology, such as EEG, gives rise to in relation to neuroscience and education. Furthermore, the present study may also contribute to understanding how the specific equipment and software used in this research might further aid in the research of brain functioning while pursuing different musical activities.

2. Framework

Musical improvisation may be defined as "the art of performing music spontaneously, without the aid of manuscript, sketches or memory" [7] (p. 19). While this activity was once deemed relevant for educating a western classical instrumentalist, from the latter half of the nineteenth century, it is normally overlooked in current western classical music education contexts [8,9]. However, improvisation is a complex task that involves performing difficult motor movements and making spontaneous choices that fit a musical context. Based on these demands, an expected result in the functioning of the brain during musical improvisation could be an activation of the areas that both control behaviours and plan complex cognitive tasks. On the contrary, fMRI has shown that musical improvisation correlates with a deactivation of the part of the brain called the dorsolateral prefrontal cortex (DPC) [10]. If, on the other hand, the musical improvisers are given a task to improve their control over their improvisations by, for example, rhythmic constraints, the activity in the DPC increases [11]. Accordingly, Landau and Limb [10] suggest that improvisation is best performed if pursued in a context of musical freedom (i.e., without constraints or focus on additional tasks) to foster a 'flow state' while improvising.

Among the few works related to our research, Limb and Braun [12] investigated the neural activity of professional jazz pianists during improvisation. By means of fMRI, they found a strong similarity in the activity of the brains of their participants. Moreover, they found a deactivation in the aforementioned DPC. To compare the brain activity between improvisation and playing music already memorised, the six participants in their study were assigned scores to memorise before the experiment. One of these pieces was a standard jazz song, and the other was a C major scale, which was to be played up and down in a specific tempo. Regarding the improvisations, one was limited to the C major scale within an octave, and the other was a free improvisation over the harmonies of a jazz song. Interestingly, similar brain activity during the improvisation experimental condition was identified regardless of the type of improvisation, which suggests that the activity in the brain while improvising was independent of the complexity of the improvisation. Moreover, Müller et al. [13] found that improvisers who play together (i.e., as in chamber music) reach a significant synchronisation in their brain signals based on EEG measurements.

By assessing the alpha-band EEG, Lopata et al. [14] investigated the differences in brain activity between musical improvisation and other activities, such as listening and playing music. Their results confirm a significant increase in the alpha-band activity during improvisation in both skilled and non-skilled improvisers. Furthermore, the effect is amplified for musicians with formal training in improvisation. In the same vein, musical improvisatory tasks seem to induce a different activity in the theta, alpha, and beta frequency bands in comparison with just playing scales on the guitar [15].

Regarding previous studies with aims comparable to ours that made use of the same equipment (Emotiv, model Insight), Bailey et al. [16] measured emotional reactions to outdoor physical activities. Data were collected in terms of arousal and valence using EEG and self-reported values. Physiological reactions were also measured. Interestingly, the values measured using the EEG were in better agreement with the subjects' self-reported values than those gathered by physiological responses. Accordingly, their study supports the use of the Emotiv equipment for investigating brain activity in a similar way to our study. Moreover, an experiment using Emotiv's other commercially available but slightly more expensive product, named EPOC, was conducted by Lievesley et al. [17]. The purpose of the study was to compare how EPOC performed in situations where participants with different types of mobility impairments needed help. The experiment tested two different conditions. First, EPOC's function for reading facial expressions was assessed in comparison to activating a pressure sensor. The result suggests that pressing the sensors was more effective than using the facial-reader to allow the participants to communicate. The second part of the experiment was designed to examine EPOC's mental commands. By means of a detection algorithm, EPOC purportedly enables a subject to communicate with a computer through thoughts alone. This use is particularly interesting for patients who are completely paralysed. Lievesley et al. [17] concluded that this function was promising; Emotiv's EPOC is not expensive and proved to be effective for their purpose. In addition, Bailey et al. [16] estimated that the states of mind, as measured by the equipment, agreed well with independently reported subjective values. Furthermore, EEG measurements were also found to correlate with subjective assessments better than tools that measured physiological responses such as galvanic skin response and heart-rate variability [16]. This evidence supports the use of EEG in combination with self-reported measures as a reliable method for measuring brain activity in different situations.

The advantage of Emotiv Insight is that unlike other commercially available and similar PEEGTs such as Muse or NeuroSky, it has more electrodes, which increases the amount of data [16]; owing to the two Emotiv Insight electrodes on the forehead, it can measure asymmetric activity in the frontal lobe, which has been validated as a way to measure arousal [16]. Other advantages supporting its usage and portability include that it is easy to assemble, easy to connect to a computer, and relatively cheap. Moreover, Emotiv Insight uses semi-dry electrodes; many EEG measuring devices require the electrodes to be soaked, thus complicating the assembly phase and the equipment use in general.

In conclusion, the research literature is scarce on the investigation of brain functioning in the activities regarded in the present study. Moreover, while its exploration by means of the selected equipment has still not been reported in the extant research, several studies investigating non-musical activities [15,16] support the possibility of using this equipment in researching our aim. According to the extant literature, the equipment is also well suited to be used in combination with self-reported subjective values and seems a great option for portable and reliable measurements of EEG [16].

3. Methodology

A description of the procedures, the involved variables, the participant, and the collection of data in the present study is detailed below.

3.1. Research Design and Participants

The research design and procedures of this study have undergone ethical review by the ethics committee of the University of Malaga. The research design of this study draws upon a single-case experimental study [18]. Despite its disadvantages, this research approach was chosen in light of certain advantages related to our specific topic; while generalisation of the results would only be possible through naturalistic procedures [19], single-case experimental designs are particularly convenient for exerting great control over confounding variables and allow in-depth investigation of a case [20]. The participant was selected purposefully in the search for an information-rich case [21] based on characteristics deemed well-suited for our research aim, his commitment to the experimental procedures, and his consent to participate in the study. The selected case is a male of 23 years who holds a degree in piano playing and who was educated in both western classical music and jazz. The participant is an accomplished music improviser, sight-reader, and regular meditator; the two first aspects are accredited by his education and professional performance, and the last by his own declarations. In our judgement, these characteristics — his skills in meditation, sight-reading, and improvisation, as well as his commitment with the demanding, experimental procedures—match the requirements of the experimental conditions described in the next section. Furthermore, the participant is included as a co-author of this study, given his interest in this area of research and his contributions to the present study.

3.2. Data Collection

For the collection of data, a non-randomised quasi-experiment was designed [22]. The two different musical activities that form the basis of the experiment are sight-reading and improvising at the piano. The improvisation was completely free, with no prior indications or constraints. The scores for the sight-reading experimental condition consisted of piano music that typically contained no more than three voices by the composers Johann Sebastian Bach (1685–1750) and Joseph Haydn (1732–1809), which were not in the repertoire of the participant according to consultation. Each experimental session took approximately 70 min and consisted of different parts: (a) the participant was equipped with the Emotiv helmet for registering data, and the equipment was tested (normally 10 min), (b) freely warming up at the instrument (up to 30 min), (c) musical sight-reading (10 min), (d) mindfulness meditation (approximately 10 min), and (e) improvisation (10 min). However, the place of (c) and (e) were exchanged in alternate sessions. In addition, a logbook aimed at data triangulation [23] was completed by the subject after each experimental instance. The participant was instructed to write freely about subjective feelings in relation to the two experimental conditions, including his emotions and his body sensations. Each instance of the experiment was carried out in the same room, with the same piano, and at approximately the same time of the day. The experiment was repeated $n = 14$ times, of which $n = 6$ were discarded for Emotiv connectivity problems or unexpected interruptions in the experimental conditions, such as the participant stopping and coughing or the computer freezing. Accordingly, $n = 8$ instances were deemed as fully reliable and included in the analysis.

3.3. Involved Variables and Analysis

The independent variables consist of the two aforementioned experimental conditions: musical sight-reading and improvisation. The data was registered by the Emotiv Insight helmet, adequately placed on the participant's head. The helmet includes five electrodes that communicate with a portable Asus computer via Bluetooth. The dependent variables were the six offered by the EmotivPro software, named 'excitement', 'interest', 'stress', 'engagement', 'attention', and 'meditation'. These variables are internally calculated by a non-public algorithm developed and tested by the Emotiv company to supposedly reflect alterations in the functioning of the brain in real-time. Regarding each of these metrics, Emotiv [24] states the following: the variable 'excitement' corresponds to the psychological construct of 'arousal', and 'interest' corresponds to that of 'valence'. These are the two dimensions in Russell's multi-dimensional model of emotions, in which arousal describes how strong an emotion is, and valence, whether it is positive or negative [25,26]. Equally, according to Emotiv [24], the variable 'stress' estimates the degree of comfort/anxiety experienced by the difficulty of performing a task; 'engagement' estimates the 'degree of presence' in the actual moment; 'attention' estimates the degree to which the attention is focused on one task at a time; and finally, the variable 'meditation' offered by the Emotiv software concerns the level of relaxing or resting when pursuing an activity. The quantitative analyses were pursued through robust statistics in searching for correlations and aided by the software SPSS v. 21. The qualitative analysis of the logbook was pursued through thematic analysis by means of open coding and constant comparison [27].

4. Results

The results are presented in the following order: (1) descriptive analysis of the involved variables, (2) relational analysis of each of these variables in comparing the sight-reading and improvisation experimental conditions, and (3) analysis of the logbook.

4.1. Descriptive Analysis

The descriptive analysis of the quantitative variables that were involved in the present study is presented in Table 1.

Table 1. Descriptive statistics. In all instances, variable_1 stands for its values during the improvisation experimental condition, and variable_2 stands for that during the sight-reading one.

Descriptive Statistics				
	Mean	**Std. Deviation**	**Minimum**	**Maximum**
excitement_1	0.40	0.10	0.30	0.62
interest_1	0.57	0.13	0.45	0.87
stress_1	0.36	0.07	0.27	0.50
engagement_1	0.53	0.09	0.39	0.64
attention_1	0.32	0.08	0.21	0.45
meditation_1	0.36	0.18	0.19	0.67
excitement_2	0.32	0.09	0.19	0.44
interest_2	0.57	0.08	0.46	0.69
stress_2	0.37	0.06	0.26	0.49
engagement_2	0.54	0.10	0.39	0.72
attention_2	0.31	0.07	0.22	0.42
meditation_2	0.42	0.13	0.21	0.67

4.2. Comparison of Sight-Reading and Improvisation

We pursued multiple Wilcoxon tests for comparing the variables 'excitement', 'interest', 'stress', 'engagement', 'attention', and 'meditation' in regard to the two experimental conditions (sight-reading versus improvisation). This test was selected based on the low number of measurements (n = 8) and its adequacy for assessing comparisons of non-normal data [28]. The results of the rank analysis are grouped for all of the variables and are presented in Table 2. Likewise, the results of the significance analysis in comparing the experimental conditions are grouped and presented in Table 3.

Table 2. Rank analysis of the variables involved in sight-reading and improvisation experimental conditions, where (a) excitement_2 < excitement_1, (b) excitement_2 > excitement_1, (c) excitement_2 = excitement_1, (d) interest_2 < interest_1, (e) interest_2 > interest_1, (f) interest_2 = interest_1, (g) stress_2 < stress_1, (h) stress_2 > stress_1, (i) stress_2 = stress_1, (j) engagement_2 < engagement_1, (k) engagement_2 > engagement_1, (l) engagement_2 = engagement_1, (m) attention_2 < attention_1, (n) attention_2 > attention_1, (o) attention_2 = attention_1, (p) meditation_2 < meditation_1, (q) meditation_2 > meditation_1, (r) meditation_2 = meditation_1.

Ranks				
		N	**Mean Rank**	**Sum of Ranks**
excitement_2—excitement_1	Negative Ranks	6 [a]	4.83	29
	Positive Ranks	2 [b]	3.50	7
	Ties	0 [c]		
interest_2—interest_1	Negative Ranks	4 [d]	4.00	16
	Positive Ranks	4 [e]	5.00	20
	Ties	0 [f]		
stress_2—stress_1	Negative Ranks	3 [g]	5.33	16
	Positive Ranks	5 [h]	4.00	20
	Ties	0 [i]		
engagement_2—engagement_1	Negative Ranks	2 [j]	6.50	13
	Positive Ranks	6 [k]	3.83	23
	Ties	0 [l]		
attention_2—attention_1	Negative Ranks	4 [m]	5.50	22
	Positive Ranks	4 [n]	3.50	14
	Ties	0 [o]		
meditation_2—meditation_1	Negative Ranks	3 [p]	4.00	1200
	Positive Ranks	5 [q]	4.80	2400
	Ties	0 [r]		

Table 3. Wilcoxon signed ranks test (a) based on positive ranks, (b) based on negative ranks.

	Excitement_2—Excitement_1	**Interest_2—Interest_1**	**Stress_2—Stress_1**	**Engagement_2—Engagement_1**	**Attention_2—Attention_1**	**Meditation_2—Meditation_1**
Z	−1.54 [a]	−0.28 [b]	−0.28 [b]	−0.70 [b]	−0.56 [a]	−0.84 [b]
Asymp. Sig. (2-tailed)	0.12	0.77	0.77	0.48	0.57	0.40
Exact Sig. (2-tailed)	0.14	0.84	0.84	0.54	0.64	0.46
Exact Sig. (1-tailed)	0.07	0.42	0.42	0.27	0.32	0.23
Point Probability	0.02	0.05	0.05	0.04	0.04	0.03

4.3. Analysis of Logbook

The adjectives used in the logbook were always positive. Furthermore, the subjective experience of improvising was generally associated with a higher feeling of arousal by the participant. While the sight-reading experimental condition is commonly regarded with expressions such as "I felt focused", in relation to the improvisation one, the participant typically declared experiencing higher levels of "attention" and "interest". Furthermore, the participant consistently used expressions that describe sight-reading as a 'focused activity', while he described improvisation with words denoting 'committed' feelings. Indeed, the words mentioned in relation to improvisation are, for example, "fun", "inspired", or "flow"; while the words used for describing the sensations in relation to the sight-reading experimental condition are more often "concentration" or "focus".

5. Discussion

The analysis of the data retrieved by EEG revealed no statistically significant differences in the functioning of the brain between the sight-reading and the improvisation experimental conditions. While the null hypothesis that regards no difference in brain functioning cannot be rejected in the analysed case, we consider that the observed trends in the quantitative data are supported by the qualitative data and, therefore, are worth discussing despite their non-statistical significance. First, the variable that shows the highest difference in relation to the two experimental conditions was 'excitement'. Moreover, when comparing the mean ranks, the variables were typically higher for the improvisation experimental condition. Accordingly, the analysis of qualitative data in this study supports this last finding, provided that the adjectives describing feelings of excitement typically appear in relation to the improvisation part of the experiment.

In relation to the extant research, the absence of statistically significant differences in the functioning of the brain between different musical activities would contradict previous results that suggest a deactivation in DPC while improvising music [10,12], as well as an increase in activity in the alpha-band [14] and in the theta and beta bands [15]. We hypothesise that this discrepancy may be explained by several different theories. A first theory might rely on the possibility that the trends observed in our data would turn into statistically significant differences in comparing the experimental conditions if the number of experimental instances was substantially increased. However, although a different brain activity might exist between the studied experimental conditions, this would be difficult to detect by EEG. Given that previous research on improvisation that was (a) based on fMRI and (b) with only a few experimental instances has been successful in finding differences in brain activity while improvising [10,12], if this first theory could be verified, then fMRI should be suggested as a more accurate technology for measuring the examined differences. The reason for this may well lie in the fMRI's capacity to investigate the interior of the brain, which would, in this case, outperform the EEG's superior temporal resolution in assessing the electrical functioning of the brain.

A second hypothetical theory for justifying the aforementioned discrepancy between our results and the extant research may lie in the individual characteristics of the participant selected in the present study. It might be possible that, given that the participant is an accomplished improviser and sight-reader, both activities would not suggest many differences in his particular brain functioning, while those differences would indeed be present if considering another participant/other participants with different attributes. However, this second hypothetical theory would contradict the study of Limb and Braun [12]; they found a strong similarity in the brain functioning of their six participants when improvising at the piano. Moreover, their participants were skilled improvisers, as was the participant in the present study. Furthermore, this hypothesis would also contradict the study of Müller et al. [13] regarding the similarities found in the brain functioning of guitar improvisers.

A third hypothetical theory resulting from the comparison of our results with previous research may lie in measurement inaccuracies. It might be possible that the number of electrodes provided by Emotive Insight was not sufficient. If such is the case, other popular equipment, such as Muse or Neurosky, would automatically be disqualified for investigating our aim. Alternatively, within this third hypothesis, the algorithms that internally calculate the variables offered by Emotive Insight might not function well in discerning the differences between the two experimental conditions that we examined in this study. If this last were true, and given the success of the equipment in measuring different experimental conditions in other cases, it would favour the fact that Emotiv Insight is better suited for assessing the electrical activity of the brain regarding other physical activities [16]. Finally, in relation to this third hypothesis, it would also be possible that 'too much' is happening in the brain during the 10 min duration of each experimental condition, even if the participant is fully concentrated on the executed activity. If such is the case, altering the experiment by counterintuitively providing shorter timeframes for each experimental condition would maybe lead to more accurate results instead of the opposite.

In summary, while we were unable to find statistically significant differences in the electrical activity of the brain between music improvisation and sight-reading, the trends found in the quantitative data, the methodological triangulation pursued by our analysis of self-reported qualitative data, and the extant research [10,12,14,15] concurrently suggest the existence of such differences. In addition, the variable 'excitement' offered by the Emotiv software is hypothesised to be the most accurate tool to measure such possible differences among the involved variables. Furthermore, we have discussed different alternatives for explaining our results that regard the limitations of Emotiv Insight, the particular characteristics of the selected participant in this study, and the experimental conditions. The limitations of this study are partly shared with case studies [18], as it is impossible to make generalisations with a limited, non-randomised sample and by the small number of repetitions of the experimental conditions in the present study. However, these limitations are partly compensated by the superior control of confounding variables and the suitability of the sample provided by the selection of an information-rich case [20,21]. Additional limitations to our results are discussed as stemming from the method for measuring the activity of the brain. Indeed, we argue that fMRI might be more suited for our purpose in the present study, or that the variables offered by the Emotiv software might be of insufficient quality for discrimination under our experimental conditions.

Despite the aforementioned limitations, the results of this study provide preliminary evidence on the possibilities of using EEG, Emotiv software, and Emotiv Insight hardware for measuring the brain activity between different musical activity conditions. Moreover, the qualitative results and the quantitative trend found in relation to the increased excitement during the improvisation experimental condition (albeit not statistically significant) supports the value of improvisation in music education; pursuing activities that increase student excitement would help in developing engagement and motivation in similar cases [29]. On the contrary, while score-reading is typical in instrumental music education contexts, improvisation is not traditionally a part of one-to-one instrumental music tuition [30]. Furthermore, we hypothesise that the typical absence of improvisation in the education of western classical music instrumentalists historically may contribute to the traditionally high abandonment rates of instrumental music education [31].

Further research in this area is needed and, in view of our discussion, may rely on replicating this study with a higher number of participants and/or experimental instances, comparing fMRI and EEG data in relation to the examined experimental conditions, or trying another PEEGT and/or another variable in the measurement of EEGs.

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