Binaural music and educational attainment: Evidence from longitudinal and quasi-experimental data

Música binaural y logro educativo: evidencia con datos longitudinales y cuasiexperimentales

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Abstract:

This article investigates the impact of background binaural music on educational attainment within the context of a natural experiment. In a university business school, 73 undergraduate students participated in this study, providing a maximum of 707 observations at 16 points in time. The students were divided into three groups (Microeconomics A and B, and International Economics) and were further categorized into control and experimental groups at different stages of the courses. All students attended classes from January to June 2021, with the addition of binaural music as a treatment in either the first or second part of the courses (divided into three parts). After each lecture, students completed a multiple-choice quiz designed to assess their learning during the lecture. Utilizing t-tests for mean comparisons and panel data econometric techniques, the study found that the scores of the experimental groups were significantly higher than those of the control groups. Overall, binaural music was observed to increase quiz scores by 8 to 20 basis points.

Keywords: economics, educational attainment, binaural music, natural experiment, longitudinal studies.

Resumen:

Este artículo investiga el impacto de la música binaural de fondo en el logro educativo dentro del contexto de un experimento natural. En el estudio, participaron 73 estudiantes de una escuela de negocios universitaria, con un máximo de 707 observaciones en 16 puntos en el tiempo. Los estudiantes fueron divididos en tres grupos (Microeconomía A y

Date of receipt of the original: 2024-03-31.
Date of approval: 2024-07-05.
Please, cite this article as follows: Tovar-García, E. D. (2024). Binaural music and educational attainment: Evidence from longitudinal and quasi-experimental data [Música binaural y logro educativo: evidencia con datos longitudinales y cuasiexperimentales]. *Revista Española de Pedagogía, 82* (289), 667-693. https://doi.org/10.22550/2174-0909.4164

B, y Economía Internacional) y categorizados, además, como grupos de control y experimentales en diferentes etapas de los cursos. Todos los estudiantes asistieron a clases desde enero hasta junio de 2021, con la adición de música binaural como tratamiento en la primera o segunda parte de los cursos (divididos en tres partes). Después de cada clase, los estudiantes completaban un examen rápido *(quiz)* de opción múltiple diseñado para evaluar su aprendizaje durante la clase. Mediante pruebas *t* para comparaciones de medias y técnicas econométricas de datos de panel, se descubrió que las puntuaciones de los grupos experimentales fueron significativamente más altas que las de los grupos de control. En general, se observó que la música binaural aumentaba las puntuaciones de los exámenes rápidos entre 8 y 20 puntos básicos.

Palabras clave: economía, logro educativo, música binaural, experimento natural, estudios longitudinales.

1. Introduction

Gaining and keeping students' attention are major concerns when teaching economic theory at the university level, as should be the case for many other subjects. It is well known that millennial and post-millennial generations (digital natives) have difficulties paying attention during lectures (Koponen, 2019; Sharma et al., 2020). This challenge became particularly complex during and shortly after Covid-19, especially with the current hybrid teaching models, which involve both in-person and online students (Keržič et al., 2021; Nieto-Escamez & Roldán-Tapia, 2021). To attract attention, various pedagogical strategies are useful, such as joking, asking interesting questions, team activities, exercises, and quizzes (Briscoe et al., 2022; Castillo-Montoya, 2019; Halawa et al., 2020; Schroeder et al., 2007). In this context, music has been highlighted as a useful tool for concentrating and studying, even in the classroom (Dosseville et al., 2012).

Music can evoke emotions and enhance mood, contributing to better concentration, motivation, and overall well-being, potentially impacting academic achievement (Mega et al., 2014; Pekrun et al., 2002). In addition, listening to music and/or participating in musical activities can reduce stress and anxiety levels, influencing student's ability to focus and perform well academically (Algailani et al., 2023; McBride & Greeson, 2023; Ye et al., 2019). Particularly, instrumental classical music has been shown to reduce stress (Pelletier, 2004) and is useful for solving mathematical tasks (Pavlyugina et al., 2012). Importantly, empirical evidence suggests its positive impact on lecturing (students learn better) (Dosseville et al., 2012).

In educational research, the relationship between music and cognition is a subject of growing interest (Holmes, 2021). Nevertheless, the evidence on the impact of music on cognitive performance is mixed and varies depending on

the type of music, the task being performed, and the population under study (Cheah et al., 2022). Overall, the literature suggests that music has positive effects on different aspects of academic performance (Antony et al., 2018; Ishiguro et al., 2023).

Having said this, recently, binaural music has gained popularity in social networks, arguing its efficiency and efficacy in improving memory and concentration for studying. As such, binaural beats have reached a broader audience by incorporating this technology into music and claiming their usefulness for enhancing focus (Filimon, 2010; Rahman et al., 2021; Sharma et al., 2017). Overall, binaural beats may impact emotional states, physiological responses, and cognitive functions, making binaural music (the masking of binaural beats with music) a relevant subject of study due to its potential effects on memory, attention, stress, anxiety, pain perception, and many other aspects (Garcia-Argibay et al., 2019). Nonetheless, binaural beats have also been criticised due to their potential to cause discomfort (Rahman et al., 2021).

As new technologies and pedagogical tools emerge, the use of auditory stimuli on cognitive performance has also become a subject of growing interest (Cheah et al., 2022; Dosseville et al., 2012; Hallam & Price, 1998; Hickey et al., 2020). The current research contributes to this literature by examining the impact of background binaural music on educational attainment, assessed by multiple-choice quiz scores administered after lectures at different time points. Importantly, this research is based on a natural experiment, differing from the self-reported survey research that characterizes much of the existing literature. For this research, the covid-19 pandemic and the need to innovate in the teaching-learning process allowed the use of binaural music in class, providing longitudinal and quasi-experimental data, whose analysis favours the positive impact of binaural music on educational outcomes. Therefore, this research increases credibility, allowing for an in-depth exploration of the potential influence of binaural music on cognitive performance in real-world educational settings.

The rest of the article is structured as follows. Section 2 presents a literature review on education, music, and binaural beats. Section 3 presents the method: participants, materials, procedure, and data analysis (descriptive statistics, *t*-test for mean comparisons, and regression models with panel data). Section 4 presents the main results and section 5 discusses them, underlining limitations and future research lines. Finally, it concludes with some recommendations.

2. Literature review

Music education is associated with creativity (Burnard & Younker, 2004; Gershon & Ben-Horin, 2014). The improvisational nature of musical activities and the exploration of various

musical elements contribute to the development of creative thinking skills positively impacting problem-solving and critical thinking skills, which is necessary for academic success (Albar & Southcott, 2021; Burnard & Younker, 2004). In addition, music education is linked to socioemotional development (Blasco-Magraner et al., 2022; Ilari, 2020), particularly supporting child development, where collaborative musical experiences, such as group performances, help in developing interpersonal skills, teamwork, and empathy (Ilari et al., 2019). These social skills are relevant to students' overall development and can influence academic success. Likewise, the learning of a musical instrument is linked to cognitive skills, including memory, attention, and spatial-temporal abilities (Rose et al., 2019; Suárez et al., 2016).

In the literature, the positive association between music education and mathematical proficiency is also emphasized (Gillanders & Casal, 2020; Guhn et al., 2019; Jaschke et al., 2013). Music implies understanding patterns, rhythm, and proportions, skills that may be transferred to mathematical reasoning. In general, students who participate in music education exhibit good mathematical skills (Baker et al., 2023; Brazhnikova, 2016).

The emotional and psychological impact of music on students is another important area of study (Algailani et al., 2023; Cheah et al., 2022; McBride & Greeson, 2023; Mega et al., 2014; Pekrun et al., 2002; Ye et al., 2019). Music affects emotions and exposure to music is associated with improved mood and reduced stress and anxiety levels, positively influencing student's ability to focus, engage, and perform well academically (Mega et al., 2014; Pekrun et al., 2002).

Nevertheless, the relationship between music and academic achievement is complex, with several findings under debate (Cheah et al., 2022). For instance, the Mozart effect (Rauscher et al., 1993) refers to findings indicating that listening to Mozart's music, particularly the *Sonata for two pianos in D major, K. 448*, composed in 1781, can induce short-term improvement in certain types of mental tasks, known as *spatial-temporal reasoning* (Beauvais, 2015; Stough et al., 1994). The Mozart effect is not limited to classical music or the music of the Viennese composer, and it is not without criticism (Nantais & Schellenberg, 1999; Thompson et al., 2001; Waterhouse, 2006).

Overall, integrating music into educational curricula can support student interest and engagement (Algailani et al., 2023; Baker et al., 2023; Hallam & Price, 1998; Ishiguro et al., 2023). The motivation produced by a positive musical experience has positive indirect effects on educational achievement by promoting an active and engaged learning environment. Dosseville et al. (2012) present evidence of the positive impact of classical music on the academic performance of undergraduate students

during learning. This genre of music (its tempo, tonality, modes, etc.) appears to positively influence the learning environment and the affective states of students, thereby helping their comprehension of lectures and improving overall learning outcomes.

In general, the literature supports the positive impact of music on educational outcomes, but potential challenges should be acknowledged, including issues related to resource allocation, student interest, and the integration of music into diverse educational settings. In this context, binaural music has recently emerged and calls for the understanding of its potential benefits and challenges in educational settings, which is crucial for educators, policymakers, and researchers.

2.1. Binaural beats

Binaural beats are two sounds of slightly different frequencies, one for each ear, processed by the brain creating the sense (illusion) of a third sound (Filimon, 2010; Garcia-Argibay et al., 2019; Ingendoh et al., 2023; Lee-Harris et al., 2018; Orozco et al., 2020; Sharma et al., 2017). Heinrich Wilhelm Dove (1803–1879) discovered binaural beats in 1839 and Gerald Oster (1918-1993) tested them on the encephalograph (Filimon, 2010). The brain releases electric impulses, brain waves, which determine states of conscience. These waves are classified into four fundamental types: delta, theta, alpha, and beta, but the gamma frequency is also mentioned in the literature (2010).

It is claimed that the brain responds to binaural beat stimuli by synchronizing its own electrical cycles with the audio (Sharma et al., 2017). Although debated, the brainwave entrainment hypothesis states that external stimuli at specific frequencies cause the brain's electrocortical activity to oscillate at the same frequencies. These brain responses can be measured primarily using two strategies: auditory steady-state responses or auditory frequency-following responses (Ingendoh et al., 2023; Orozco et al., 2020). As such, "the cognitive effects of binaural beats are attributed to their capacity to drive neural oscillations at the beat frequency through differential hemispheric synchronization frequencies" (Orozco et al., 2020, p. 2). However, the evidence suggests that the effects of binaural beats are influenced by factors such as the frequency, the duration of exposure, and the type of masking used for binaural beats (Garcia-Argibay et al., 2019; Orozco et al., 2020).

Having said this, it is expected that binaural beats facilitate moving from one state of consciousness to another. Nowadays, individuals are predominantly in the beta wave frequency, which is useful for analytical thinking because it is an alert state, but also it implies tension, anxiety, and stress. Consequently, the brain usually attempts to transform beta waves into alpha ones, which are associated with calm and a receptive mind, supporting mental focus and the learning process (Filimon, 2010; Sharma et al., 2017).

Based on a meta-analysis, Garcia-Argibay et al., (2019) found that binaural beats can influence mental states and cognition. There is evidence suggesting that exposure to binaural beats leads to psychophysiological changes, such as reduced anxiety and stress levels, and increased creativity. Moreover, binaural beats are associated with improvements in memory, attention, and pain perception (Garcia-Argibay et al., 2019; Orozco et al., 2020).

Similarly, the role of binaural music (music embedded with binaural beats) has been studied in various fields, such as music therapy to enhance people's health (Filimon, 2010; Rahman et al., 2021). The evidence suggests that binaural music decreases anxiety in surgical patients, such as those undergoing cataract surgery (Wiwatwongwana et al., 2016) and helps manage hypertension (Wichian et al., 2021). Bae et al. (2023), specifically, demonstrated its anxiety-reducing effects in surgical patients.

While binaural music, i.e., "binaurally recorded sounds, binaural beats, a slow tempo, and gradual changes" (Lee-Harris et al., 2018, p. 1), is often associated with relaxation, stress and anxiety reduction, and improved focus, there is no specific scientific research on its impact on academic achievement. However, we can assume potential effects based on related research.

Low levels of stress positively influence attention and cognitive performance. Consequently, students who experience lower stress levels may be better equipped to concentrate, study effectively, and perform well academically (Algailani et al., 2023; McBride & Greeson, 2023; Ye et al., 2019). Similarly, anxiety can interfere with academic performance, for example, negatively affecting attention, memory, and problem-solving abilities. Therefore, low levels of anxiety create conditions for effective learning and academic performance (Pekrun et al., 2002). Furthermore, listening to binaural music may also enhance mood and increase motivation (Lee-Harris et al., 2018), positively affecting academic engagement and perseverance in the face of challenges to academic achievement (Mega et al., 2014; Pekrun et al., 2002).

Note that, primarily, anecdotal evidence supports the positive effects of binaural music on focus and relaxation for studying. Consequently, rigorous scientific research is needed to establish clear causation and quantify the extent of these effects. As with any intervention, it is advisable to consider individual needs, preferences, and the context in which binaural music is used concerning academic pursuits. As research in this field continues to advance, the study of the relationship between binaural music and academic achievement will contribute to the ongoing improvement of educational practices. Importantly, individual preferences play a significant role, and not everyone may benefit from or enjoy binaural music (Rahman et al., 2021).

In this context, this article contributes to the literature by testing the impact of binaural music on the educational outcomes of university students, using their classes of international economics and microeconomics and building longitudinal data from a natural experiment in times of covid-19.

3. Method

Artificial intelligence was occasionally used in different sections of the article exclusively to improve writing and readability (OpenAI, 2023).

The covid-19 crisis represented a succession of new challenges at all levels of education, demanding pedagogical innovations (Keržič et al., 2021; Nieto-Escamez & Roldán-Tapia, 2021). Accordingly, different strategies to capture and maintain students' attention were explored, including the use of background music at the beginning of the lockdown (from March to December 2020). This decision was a result of the necessity to choose between noise or music due to the disturbances present in the household environment, such as crying babies or unexpected interruptions. Initially, instrumental classical music was employed to reduce stress based on existing research (Pelletier, 2004), and the positive effects observed in both lecturing (Dosseville et al., 2012) and mathematical problem-solving tasks (Pavlyugina et al., 2012), as well as the Mozart effect (Beauvais, 2015). However, due to the exigencies of the crisis, the exploration of strategies led to the discovery of binaural music (Filimon, 2010; Rahman et al., 2021; S. Sharma et al., 2017). This shift from classical to binaural music resulted in a positive experience, seemingly improving the average academic performance of students. However, this perception was based solely on anecdotal evidence, generating a pilot study to gather data. In addition, students did not object to the use of background music; instead, they supported it. Consequently, a decision was made to document and formalize this natural experiment systematically in the first semester of 2021 (from January to June 2021), allowing for data collection as described below.[1]

3.1. Participants

The sample includes 73 undergraduate students, who were enrolled in the courses of Microeconomics (two groups: micro A and micro B) and International Economics. Thus, the participants were in three different groups: Microeconomics A (n = 27; 15 females and 12 males; average age 20.5), Microeconomics B (n = 25; 9 females and 16 males; average age 20.6), and International Economics (n = 21; 3 females and 18 males; average age 21.4). The students of Microeconomics were first-year undergraduate business/management students, and the students of International Economics were third year. English was the language of instruction, and the classes started on January 18 and finished on May 20 in the year 2021 (with final exams at the

beginning of June), in accordance with the academic calendar of Anonymous University.

3.2. Material

3.2.1. Online class

Given the covid-19 restrictions, Moodle was used as the learning platform and Google Meet for online classes. The lessons of Microeconomics A were on Mondays and Wednesdays, starting at 11:00 am and finishing at 12:30 pm, with 1 hour and 15 minutes of lecture, combined with synchronized slides, and using the last 15 minutes to answer general questions (if necessary). Microeconomics B was on Fridays, starting at 9:15 am, with a break from 10:30 am to 11:00 am, finishing the class at 12:30 pm, giving the last 15 minutes to general questions. In the case of International Economics, the lessons were on Tuesdays and Thursdays, starting at 7:00 am and finishing at 8:45 am, with 1 hour and 30 minutes of lecture, combined with synchronized slides, and using the last 15 minutes to answer general questions. The students had already received their classes in a very similar context in the year 2020, so they were familiar with the procedure. In addition, note that the groups are small, and the lecture is not traditional because students actively participate in class.

The topics taught in microeconomics are basic, based on Parkin's textbook. The course is divided into three parts. The first part includes the chapters on supply and demand, elasticity, and consumer theory. The second part includes the chapters on the theory of the firm, output, and costs. In partial three, the course finishes with the chapters on market structures (Parkin, 2019). Krugman's textbook is used in the case of International Economics. The first part includes chapters on international trade theory, e.g., comparative advantage, Heckscher-Ohlin model, and scale economies. The second part includes chapters on trade policy and international finance. In partial three, the course finishes with chapters on open macroeconomic policy (Krugman et al., 2018).

3.2.2. Multiple-choice quiz

At the end of each lecture of the first and second parts of the courses, in five minutes, the students answered a multiple-choice quiz (MCQ) in Moodle, which was created from the lecture material. The students answered the same questions, randomly assigned, and backtracking was prohibited to prevent copying. The students were informed that the results of the MCQs constituted 30% of their grades in the mid-term exams (partials one and two). Actually, the quizzes were only 10% of the final grade according to the syllabus, as many other assignments and partial exams were accounted for the final grade. However, this 10% figure was not emphasized to the students, who were expected to try their best on each quiz because of the 30% weighting.

In the case of Microeconomics, each MCQ consisted of three questions, two

of them type true/false, and one of them type multiple options (four answers, of which one was correct), in a 0-100 grading scale where the multiple option question equalled 40 points. In the case of International Economics, the three questions were multiple options (five answers, of which one was correct), in a 0-100 grading scale, where the value of the most difficult question (in opinion of experts) was 40 points. In total, there were 11 MCQs in the case of Microeconomics (six in the partial one, and five in the partial two) and 16 MCQs in the case of International Economics (eight in each partial).

The typical recommendations found in methodological textbooks to write the questions were followed: avoid vagueness, avoid excessively complicated questions, avoid negative stems, and use correct grammar. Nevertheless, the question types of the MCQs of Microeconomics and International Economics were different, as a response to students' background on economics and the requirements of their study programs. The students of Microeconomics passed an introductory course to economics and history of economic thought. In contrast, the students of International Economics additionally passed the courses of microeconomics and macroeconomics.

Note that partial three of the courses had a completely different pedagogical dynamic. The students were tasked with presenting topics and scientific articles, supplemented by the use of multimedia resources including videos, memes, and Kahoot quizzes. Additionally, the final exam for these courses consisted of approximately 80% of questions related to topics covered in the third partial, with the remaining 20% focused on material from the first and second partials.

3.2.3. Music

Binaural beats present two neighbouring frequencies to each ear, separately. For its part, binaural music, audio recorded using binaural beats technique, already presents the resulting frequency, summing each tone before the presentation. As a result, binaural music becomes monaural and is presented to both ears at the same time (Orozco et al., 2020). As such, this type of music was used as background music, played at low volumes to ensure it would not disturb the lecture. Importantly, Garcia-Argibay et al. (2019) show meta-regression results suggesting that it does not seem to be necessary to mask binaural beats with white noise or pink noise in terms of effectiveness. Therefore, the choice of masking method (white noise, pink noise, music) may not significantly impact the effectiveness of binaural beats, providing flexibility in how binaural beats are presented in various settings.

Thus, binaural music represents the treatment condition compared to the control condition of no music. Although students were not formally informed about the presence of music (though

they obviously noticed it), they listened to the music a few minutes before the start of class and during the lecture. Among the various options available on YouTube, a piece of music from Greenred Productions, with alpha binaural beat frequency, was selected after brainstorming, considering factors such as the number of views, likes, and comments.[2]

3.2.4. Previous tests on economics

At the beginning of the semester, all students completed general exams on economics to control for prior knowledge of the subject. In the case of Microeconomics, students answered in 75 minutes a test with 18 questions on the basic topics of chapters 1 and 2 of Parkin´s textbook. They answered the same questions, randomly assigned, and backtracking was prohibited to prevent copying, in a 0-100 grading scale (Microeconomics A: mean *(ME)* = 75.19, standard deviation *(SD)* = 13.41; Microeconomics B: *ME* = 82.71, *SD* = 16.83).

Similarly, in the case of International Economics, students answered three tests. Two of them on microeconomics, the first one on basic topics, the same test for students in Microeconomics (*ME* = 52.63, *SD* = 8.94), and the second one on supply, demand, and elasticity (20 questions, *ME* = 57.63, *SD* = 16.17). The third test was on macroeconomics: aggregate supply, aggregate demand, IS-LM model, and fiscal and monetary policies (25 questions, *ME* = 48.42, *SD* = 15.13).

3.2.5. Background questionnaire

After the mid-term exams and before the topics of the third partial began, all students completed a background questionnaire to provide control variables (see Table 1). In addition to general background data, they provided information and opinions (10-point rating scales) about the background music, difficulty of MCQs, difficulties because of covid, technical or internet issues, language concerns, and grade point average (GPA). Only at this moment were the students informed about the use of music and plans to use their data for research purposes (exclusively and on condition of anonymity). Accordingly, students provided written consent to use their MCQ results and background data. One student refused and was removed from the analysis.

3.3. Procedure

In the case of Microeconomics, binaural music was used during the lectures for group A in the first part of the course, making group B the control group. Conversely, binaural music was used during the lectures for group B in the second part of the course, with group A becoming the control group. In that manner, both groups operated as treatment and control groups, allowing intra-and inter-group comparisons. In the case of International Economics, binaural music was used in lectures during the first partial, with the quiz scores from the second partial serving as the data for the control group, allowing for only intertemporal comparisons (see Table 2).

TABLE 1. Background questionnaire.

		Micro A		Micro B		International Economics	
		ME	*SD*	*ME*	*SD*	*ME*	*SD*
Q1	Did you notice if background music was played during the sessions before the first midterm? (1 = Yes / 0 = No)	0.93	0.26	1.00	0.00	0.95	0.21
Q2	If you noticed, on a scale from 0 to 10, where 0 represents "not at all" and 10 represents "a lot", to what extent did this music bother you? Please write a number (if you didn't notice it, write -1).	1.63	2.15	1.40	2.12	2.95	3.39
Q3	If you noticed, do you have any comments about the mentioned music?	N/A	N/A	N/A	N/A	N/A	N/A
Q4	Did you notice that during the sessions before the second midterm exam, your professor did not play the mentioned background music? 1 = Yes / 0 = No.	0.67	0.47	N/A	N/A	0.67	0.47
Q5	On a scale from 0 to 10, where 0 is "very easy" and 10 is "very difficult", how difficult were the quizzes that were answered at the end of each lesson?	6.00	1.59	6.24	1.27	7.67	1.25
Q6	On a scale from 0 to 10, where 0 is "very easy" and 10 is "very difficult", do you think it was possible to cheat by answering the quiz, specifically, having someone pass the questions or answers to you?	5.67	2.80	7.84	1.46	7.95	1.99
Q7	On a scale from 0 to 10, where 0 is "strongly disagree" and 10 "strongly agree", do you think it was necessary to pay attention in class to be able to answer the quiz correctly?	9.41	0.91	9.36	1.05	9.19	1.53

Revista Española de Pedagogía
year 82, n. 289, September-December 2024, 667-693

Q8	On a scale from 0 to 10, where 0 is "very easy" and 10 is "very difficult", how difficult has it been for you to study the subject (specifically the economics class) as a result of the covid-19 crisis?	7.37	1.57	7.76	1.50	7.14	1.49
Q9	On a scale from 0 to 10, where 0 is "very easy" and 10 is "very difficult", how difficult has it been for you to study the subject due to problems with the internet connection, audio, microphone or other technical problem?	5.89	2.56	6.40	1.88	3.95	2.94
Q10	What device did you normally use to attend the online class? Computer / laptop = 1, Phone = 2, Tablet = 3, Other = 4.	1.13	0.42	1.22	0.57	1.21	0.40
Q11	On a scale from 0 to 10, where 0 is "very easy" and 10 is "very difficult", how difficult has it been for you to study the subject because the language of instruction is English?	4.52	2.85	3.60	3.09	4.00	3.48
Q12	Is English your mother tongue? 1 = Yes / 0 = No	0.07	0.26	0.08	0.27	0.00	0.00
Q13	On a scale from 0 to 10, where 0 is "very low" and 10 is "very high", how good do you consider your level of English, especially technical, to understand economics?	7.85	1.18	7.68	1.59	7.95	1.62
Q14	What was your GPA last semester?	8.79	0.41	8.34	0.70	8.43	0.45
Q15	So far, what is your GPA this semester?	8.68	0.46	8.19	0.76	8.19	0.63

Notes: *ME*: mean; *SD*: standard deviation. N/A: not applicable. Students in Microeconomics B listened to the music in the second part of the course. GPA: Grade Point Average (scale from 0 to 10).

TABLE 2. Design of the performed comparisons.

	Partial 1	**Partial 2**	
Microeconomics A	Experimental condition	Control condition	Intra-group comparison
Microeconomics B	Control Condition	Experimental condition	Intra-group comparison
Microeconomics A versus B	Inter-group comparison	Inter-group comparison	
International Economics	Experimental condition	Control condition	Intra-group comparison

Evidently, the students did not attend exactly the same lecture. While every effort was made to explain each topic in the same manner by the same instructor, and to avoid providing extra information that could assist one group over the other in answering the MCQs, each lecture differed due to student participation. This is a limitation of this study, yet the strategy is under real conditions. Moreover, consider the use of panel data, which offers greater degrees of freedom, increased variability, reduced collinearity, enhanced efficiency, and the most important aspect: control over the researcher effect by controlling for time-invariant variables.

3.4. Data analysis

To test the impact of binaural music on the MCQ scores, first, statistical descriptive analysis and *t*-tests to compare means between the experimental and the control groups (including the intertemporal observations, for intra-group analysis) were used. Second, regression models with a dummy variable coded 1 were considered for the treatment, while the initial exams on economics and several other variables from the background questionnaire operated as control variables. The correlation coefficients amongst independent variables were low (see Table 3). Nevertheless, not all possible independent variables were entered at the same time in the regression models because of multicollinearity concerns.

Accordingly, five baseline regression models are given by equations (1) to (5), which were estimated using random effects to allow the inclusion of time-invariant variables (also supported by the Hausman test).

MCQ represents the score of the quizzes by subject according to the subscript. The subscript First partial Microeconomics A vs B signifies the inter-group comparison where Microeconomics A received the *treatment* (listening to binaural music) and Microe-

Revista Española de Pedagogía
year 82, n. 289, September-December 2024, 667-693

TABLE 3. Correlation matrix.

	MCQ score	**Treatment**	**Q1**	**Q2**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**	**Q13**	**Q14**	**Q15**	**Micro 1**	**Micro 2**	**Macro**
MCQ score (quiz)	1																		
Treatment	0.16	1																	
Q1	-0.06	-0.01	1																
Q2	-0.06	0.002	0.13	1															
Q4	-0.001	0.00	0.19	0.12	1														
Q5	-0.23	-0.004	0.12	0.32	-0.15	1													
Q6	-0.18	-0.03	0.05	-0.07	-0.02	0.30	1												
Q7	-0.02	0.01	0.02	-0.10	0.11	0.10	0.38	1											
Q8	-0.02	-0.005	0.18	0.27	-0.05	0.24	0.19	0.18	1										
Q9	0.15	-0.002	0.01	0.004	-0.22	-0.13	-0.17	-0.22	0.12	1									
Q10	0.01	-0.01	0.05	0.01	-0.06	-0.15	-0.04	-0.16	0.01	0.19	1								
Q11	-0.07	0.01	0.07	0.31	0.13	0.07	-0.06	0.02	0.17	0.33	0.03	1							
Q12	0.12	0.005	0.02	-0.06	-0.07	-0.08	-0.12	-0.10	-0.17	0.13	-0.09	-0.12	1						
Q13	0.06	0.001	-0.01	0.30	-0.20	0.17	0.00	-0.16	0.09	-0.17	-0.02	-0.45	0.16	1					
Q14	0.14	0.02	0.04	0.16	-0.11	-0.15	-0.14	-0.09	0.18	0.12	-0.16	-0.08	0.00	0.29	1				
Q15	0.18	0.02	-0.04	-0.001	-0.06	-0.22	-0.13	0.10	0.07	0.20	-0.12	-0.11	0.11	0.14	0.56	1			
Test on Micro 1	0.29	-0.01	-0.04	-0.10	-0.18	-0.32	-0.03	-0.001	0.04	0.46	-0.05	0.11	0.19	0.00	0.11	0.13	1		
Test on Micro 2	-0.06	0.00		-0.45	-0.01	-0.25	0.29	0.20	-0.07	-0.52	0.05	-0.27		-0.12	-0.07	-0.27	-0.04	1	
Test on Macro	0.09	0.00		-0.30	-0.01	0.08	0.13	0.07	0.11	-0.55	-0.07	-0.57		0.47	0.10	-0.07	-0.16	0.42	1

Note: See Table 1 for the definition of variables Q1 to Q15.

conomics B was the control group. The subscript Second partial Microeconomics A vs B signifies the inter-group comparison where Microeconomics A was the control group and Microeconomics B received the treatment. Subscript i (i = 1, ..., n) and subscript t (t = 1, ..., t) indicate the cross-section and time dimension. X represents control variables, β signifies the coefficients to be estimated, and e and v are the error terms.

$$MCQ_{it\ Score\ Microeconomics\ A} = \beta_0 + \beta_1 Treatment_{it} + X'\beta_n + e_j + v_{jt} \quad (1)$$

$$MCQ_{it\ Score\ Microeconomics\ B} = \beta_0 + \beta_1 Treatment_{it} + X'\beta_n + e_j + v_{jt} \quad (2)$$

$$MCQ_{it\ Score\ first\ partial\ Microeconomics\ A\ vs\ B} = \beta_0 + \beta_1 Treatment_{it} + X'\beta_n + e_j + v_{jt} \quad (3)$$

$$MCQ_{it\ Score\ second\ partial\ Microeconomics\ A\ vs\ B} = \beta_0 + \beta_1 Treatment_{it} + X'\beta_n + e_i + v_{it} \quad (4)$$

$$MCQ_{it\ Score\ International\ Economics} = \beta_0 + \beta_1 Treatment_{it} + X'\beta_n + e_j + v_{jt} \quad (5)$$

4. Results

Descriptive statistics and t-tests for comparing two means are shown in Table 4. In the case of intra-group comparisons between Microeconomics A and B, the t-tests indicate statistically different means, albeit with contradictory results. Specifically, for Microeconomics A, the evidence suggests higher MCQ scores for the control group, that is, higher scores for the second partial without music. Conversely, for Microeconomics B, the evidence suggests higher MCQ scores for the treatment group, that is, higher scores for the second partial with music.

In the case of inter-group, comparisons between Microeconomics A and B, for the first partial, the mean comparison between Microeconomics A (ME = 89.16) and Microeconomics B (ME = 82.17) suggests significantly higher scores for the treatment group (Microeconomics A) than for the control group (Microeconomics B). However, in the second partial, the mean comparison between Microeconomics A (ME = 94.10) and Microeconomics B (ME = 90.23) indicates statistically higher scores for the control group (Microeconomics A), with a significance level of 8% (thus, an insignificant difference under stricter p-values).

In contrast, in the case of International Economics (an intra-group comparison), a statistically significant difference in the means is evident, favouring the treatment. The mean score in the second partial was 58.05, while the mean score in the first partial (with music) was 76.67.

TABLE 4. Descriptive statistics and two-sample *t* test (with equal variances).

Microeconomía A

Group	Obs.	Mean	Std. err.	Std. dev.	[95% conf.	interval]
Control (0)	117	94.10	1.26	13.59	91.61	96.59
Treatment (1)	143	89.16	1.42	16.93	86.36	91.96
Combined	260	91.38	0.97	15.68	89.47	93.30
Difference		4.94	1.93		1.13	8.75

Difference = mean (0) - mean (1) — Degrees of freedom = 258
Ho = 0 — Ha ≠ 0 : Pr(|T| > |t|) = 0.01
t = 2.55

Microeconomics B

Group	Obs.	Mean	Std. err.	Std. dev.	[95% conf.	interval]
Control (0)	106	82.17	2.55	26.22	77.12	87.22
Treatment (1)	87	90.23	1.93	17.98	86.40	94.06
Combined	193	85.80	1.67	23.17	82.51	89.09
Difference		-8.06	3.31		-14.59	-1.53

Difference = mean (0) - mean (1) — Degrees of freedom = 191
Ho = 0 — Ha ≠ 0 : Pr(|T| > |t|) = 0.02
t = -2.43

Microeconomics first partial A vs B (group B control)

Group	Obs.	Mean	Std. err.	Std. dev.	[95% conf.	interval]
Control (0)	106	82.17	2.55	26.22	77.12	87.22
Treatment (1)	143	89.16	1.42	16.93	86.36	91.96
Combined	249	86.18	1.37	21.62	83.49	88.88
Difference		-6.99	2.74		-12.39	-1.59

Difference = mean (0) - mean (1) — Degrees of freedom = 247
Ho = 0 — Ha ≠ 0 : Pr(|T| > |t|) = 0.01
t = -2.55

Microeconomics second partial A vs B (group A control)

Group	Obs.	Mean	Std. err.	Std. dev.	[95% conf.	interval]
Control (0)	117	94.10	1.26	13.59	91.61	96.59
Treatment (1)	87	90.23	1.93	17.98	86.40	94.06
Combined	204	92.45	1.10	15.69	90.28	94.62
Difference		3.87	2.21		-0.48	8.23

Difference = mean(0) - mean(1) — Degrees of freedom = 202
Ho = 0 — Ha ≠ 0 : Pr(|T| > |t|) = 0.08
t = 1.75

International Economics

Group	Obs.	Mean	Std. err.	Std. dev.	[95% conf.	interval]
Control (0)	154	58.05	2.33	28.97	53.44	62.66
Treatment (1)	159	76.67	2.17	27.32	72.39	80.95
Combined	313	67.51	1.67	29.61	64.22	70.80
Difference		-18.61	3.18		-24.88	-12.35

Difference = mean (0) - mean (1) — Degrees of freedom = 311
Ho = 0 — Ha ≠ 0 : Pr(|T| > |t|) = 0.00
t = -5.85

Table 5 shows the main regression results of the baseline models. Overall, the regression results align with the findings of the t-tests, indicating that the evidence does not support the effectiveness of the treatment in the case of Microeconomics A, as observed in the intra-group analysis (column 1). It appears that the music had a negative effect on the MCQ scores, decreasing the average score by about five points. In contrast, the treatment shows a positive impact, resulting in an average increase of eight points in the case of Microeconomics B, as observed in the intra-group analysis (column 2).

In the first partial (column 3), where Microeconomics A serves as the treatment group and Microeconomics B as the control group, the inter-group analysis indicates a positive impact of the treatment, amounting to approximately eight points. Conversely, in the second partial (column 4), where Microeconomics B is designated as the treatment group and Microeconomics A as the control group, the coefficient of Treatment lacks statistical significance.

In the case of International Economics (column 5), the regression results suggest a positive impact of the treatment, approximately 20 points. It is also noteworthy that the majority of control variables are statistically significant only in the case of International Economics. In other words, most of the control variables lack relevance in explaining MCQ scores. This makes sense if we consider that it is the lecture content that should primarily explain quiz results.

As additional robustness checks, the analysis was replicated using fixed effects (without control variables that are time–invariant), and the coefficients of the treatment were qualitatively the same. Moreover, the analysis was replicated including different combinations of control variables (using the questions in Table 1) and time dummies. The use of time dummies negatively affected the significance of the treatment, but it was clear that time dummies overlapped the treatment presenting statistical significance and the expected sign in the treatment times (excepting Microeconomics A). In addition, in the case of Microeconomics, the analysis was replicated using gender subsamples, and the findings are qualitatively the same (not reported in tables).

Due to the nature of MCQ scores, which might tend to provide discrete variables (especially in the case of Microeconomics due to true/false questions), the regression analysis was replicated using logit regressions. MCQs with a score of 100 were coded as 1, and 0 otherwise. These results are reported in Table 6. Overall, the major findings are similar. Particularly, in the case of Microeconomics, the evidence is mixed.

Revista Española de Pedagogía
year 82, n. 289, September-December 2024, 667-693

TABLE 5. Regression results.

	(1) Microeconomics A	(2) Microeconomics B	(3) First partial Microeconomics A vs. B	(4) Second partial Microeconomics A vs. B	(5) International Economics
Treatment	-5.01***	8.32**	8.12***	-4.03	20.48***
Q2 (music disturbs)	0.18	1.05	0.31	-0.08	1.00
Q7 (pay attention)	0.02	-2.55	-1.00	-0.11	-0.30
Q8 (covid-19 issues)	-0.18	1.53	-0.57	0.62	-4.08***
Q13 (English concerns)	0.54	0.90	1.57	0.40	-0.89
Q15 (GPA current semester)	-1.08	5.13	0.21	1.97	7.88***
Test on micro 1	0.03	0.03	0.03	0.004	0.20
Test on micro 2					-0.14
Test on macro					0.42**
Constant	98.04***	39.69	76.99***	70.24***	5.04
Observations	249	172	232	189	286
n x t	23 x 11	17 x 11	40 x 6	39 x 5	19 x 16
r^2	0.03	0.06	0.05	0.03	0.19

Note: random-effects GLS regression. (*) [**] and {***} indicate statistical significance at the (10%) [5%] and {1%} levels.

TABLE 6. Logit regression results.

	(1) Microeconomics A	(2) Microeconomics B	(3) First partial Microeconomics A vs. B	(4) Second partial Microeconomics A vs. B	(5) Economía Internacional
Treatment	-0.85***	0.52$^{\psi}$	0.15	-0.56	1.67***
Q2 (MUSIC disturbs)	0.05	0.08	0.07	-0.02	-0.04
Q7 (PAY attention)	-0.02	-0.26	-0.01	-0.16	0.07
Q8 (COVID-19 issues)	-0.07	0.13	-0.09	0.10	-0.23*
Q13 (English concerns)	0.10	0.09	0.16	0.05	0.05
Q15 (GPA current semester)	-0.17	0.39	-0.06	0.24	0.40*
Test on micro 1	0.002	0.0003	-0.002	0.003	0.02
Test on micro 2					-0.005
Test on macro					0.01
Constant	2.72	-2.07	0.60	-0.24	-5.51**
Observations	249	172	232	189	286
n x t	23 x 11	17 x 11	40 x 6	39 x 5	19 x 16

Notes: logit regressions report coefficients. The odds ratio is calculated as exp(β), where β represents the regression coefficient. (*) [**] and {***} indicate statistical significance at the (10%) [5%] and {1%} levels. $^{\psi}p$-value = 0.126

Revista Española de Pedagogía
year 82, n. 289, September-December 2024, 667-693

5. Discussion

The results are robust in the case of International Economics. In contrast, the evidence is somewhat mixed in the case of the groups in Microeconomics. It is possible that the type of MCQs used to measure academic performance in these classes were not the most appropriate, particularly due to the inclusion of true/false questions where students have a 50% chance of guessing the correct answer. Regarding this issue, there is little else to be done, as the quizzes are prepared with the study program in mind rather than for experimental design purposes to test the impact of binaural music. It is important to remember that the data for this research come from a natural experiment.

In light of the argument, the background questionnaire provides more information to explain the concerns in the case of Microeconomics, and in favour of binaural music. There is an open question: "do you have any comments on the mentioned music?" In general, students enjoyed the music, typically commenting "relaxing", "it relaxed me", "I like it", "I liked it, it attracted my attention in class", "I thought it was a good idea, personally it didn't bother me or anything, on the contrary it was comfortable", "It is a very calm music that after listening to it for a while I forget about it". These comments agree with previous empirical findings suggesting that binaural music contributes to relaxation, particularly, in the case of young individuals (Lee-Harris et al., 2018).

However, a few students mentioned some kind of discomfort (one student from International Economics, four students from Microeconomics A and two students from Microeconomics B). In the case of microeconomics students, many times, the negative comment on the music was related to the quality of internet connection and sound, for example "It was distorted by the microphone and it was heard badly" "A little annoying because of the platform, it would be better if each student plays such music on their own" "Sometimes the volume of the music was very loud, I would have liked another type of music (more instrumental) but that is already an individual case" "it was heard badly and from time to time if it came to bother". Therefore, in Microeconomics, the mixed results of the effects of binaural music on academic performance could be related to the quality of internet connection and sound.

Overall, the open questions of the background questionnaire, and the statistical and regression results support the expectation of a positive influence of binaural music on academic performance. Since there are no other studies with a similar goal, it is not possible to compare and discuss the current results with prior literature specific to this kind of music. Nonetheless, in general, the results align with the Mozart effect and its sociocultural implications, while care must be taken not to interpret the findings as magical powers (Beauvais, 2015). Additionally, the findings are consistent with studies

suggesting a positive correlation between music, concentration, relaxation, mood, and educational outcomes (Antony et al., 2018; Dosseville et al., 2012; Ishiguro et al., 2023; Pavlyugina et al., 2012). In particular, the results agree with the role of instrumental classical music in lectures, which enhances the learning environment and leads to improved quiz scores, ultimately contributing to higher educational attainment (Dosseville et al., 2012).

As such, binaural music helps to focus and improves academic performance. Moreover, its positive effects are long-term, spanning practically over one semester. In contrast, previous studies have utilized classical music and data from a single lecture or exercise, providing results at a single point in time and on a short-term basis (Dosseville et al., 2012; Pavlyugina et al., 2012).

Nevertheless, it is clear that not all students enjoy binaural music (given the general comments of students cited above), which agrees with previous studies (Rahman et al., 2021). Multiple factors may be affecting the emotions and responses of listeners to binaural music; the literature has emphasized familiarity and preferences (Lee-Harris et al., 2018). Furthermore, the evidence suggests that not all individuals respond in the exact same way to the same binaural music, because individuals have different states of brainwaves (Sharma et al., 2017). Therefore, even when the policy suggestion could be to use the music in the traditional teaching-learning process, in the classroom, hybrid or not, it is more important that students are aware of the positive impact of binaural music to focus, and so to study. Thus, as some students commented in the background questionnaire, individually, each student should play the music while studying, according to their personal preferences.

5.1. Key limitations of this research and further research

First, while panel data offer numerous advantages and both dependent and independent variables are directly measured, certain control variables included in the analysis, such as grade point average, internet issues, and language concerns, are observational and self-reported. Second, explanatory variables that are time-invariant or change slowly, such as psychological variables, socioeconomic status (parental education, occupation, and income), cultural capital, and social capital, are not directly observed in the dataset. Instead, they are controlled using panel data and a quasi-experimental design. However, it would be desirable to include these variables in future research. Moreover, due to the online nature of the classes, it was not possible to ensure that students were both attending the lecture and listening to the music. Consequently, causality remains a potential concern. Therefore, further research employing a larger sample size and strict experimental designs while carefully addressing ethical concerns is necessary to better control for

causality. Nevertheless, supporting this research, it is noteworthy that general student comments about the music align with the statistical findings. The majority of students acknowledged that binaural music is relaxing and helps them to focus.

Future research should also assess the role of other musical genres, their associations with different subjects, and their effects over different timeframes. Consequently, further research should analyse the relationship between music preferences and academic performance. Moreover, future studies could provide additional insights into the benefits of binaural music by examining its effects in various contexts. For example, testing the impact of binaural music in the workplace, particularly in jobs requiring high levels of concentration. Accordingly, it would be interesting to develop other types of intervention studies using binaural music to support the major findings of this research and contribute to the development of public policies. Borrowing other words, "music is present in the everyday life of humans, and it can be used to increase the efficiency of many kinds of professional activity" (Pavlyugina et al., 2012: 354).

6. Final remarks

The classroom has been changing over the last 20 years, incorporating new tools to aid in the learning-teaching process, such as projectors, computers, and the internet. Generally, the learning-teaching process evolves over time, but the pandemic has accelerated unforeseen changes, particularly in technological advancements (Keržič et al., 2021; Nieto-Escamez & Roldán-Tapia, 2021). In this context, the findings of this research can be added to the extensive list of new and positive didactic strategies. The evidence suggests that binaural music can be highly useful as a didactic tool in the classroom, whether virtual or not, or as an additional tactic for students to focus and study at home. Accordingly, the findings of this research recommend the use of binaural background music in the classroom, analogous to music used during physical exercise or shopping at the mall. However, instructors should regulate its use based on students' signals or gestures indicating discomfort. This strategy can help students focus on the lecture, which is beneficial for some students today who appreciate frequent breaks or shorter attention spans (Bradbury, 2016).

Notes

[1] The data set for replication and direct outcomes from the software are available at the following link https://figshare.com/s/73b74b06ecb488cba7d4

[2] This piece is available at the following link: https://www.youtube.com/watch?v=mg-7netw1JuM&t=3439s

[3] Only at this moment, in the Microeconomics groups, it was noted that a few students systematically answered the MCQs quickly (in some cases after a few seconds). Therefore, these observations were removed from the analysis (outliers). By contrast, in the International Economics class, students even asked for one or two more minutes to answer the MCQs.

Author's contributions

Edgar Demetrio Tovar-García: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project Administration; Resources; Software; Validation; Visualization; Writing (original draft); Writing (review & editing).

Acknowledgements

The author would like to thank all the students who participated in this study and two anonymous reviewers for their comments. This article was completed in partial fulfilment of the degree of Especialidad en Competencias Didácticas at the Universidad Panamericana, Guadalajara, Mexico. The author is also grateful to the Head of the International Laboratory for Experimental and Behavioural Economics and all participants at the XIV International Conference on Higher Education at HSE University, Moscow. The research was prepared within the framework of the Basic Research Program at HSE University.

Competing interests

The author declares no competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript. The music selection used in this study was composed and recorded by Greenred Productions, but is freely available to the public. As such, Greenred Productions has no financial conflict of interest.

Ethical approval

Ethical approval was not sought due to issues with access to ethical review boards during the Covid-19 pandemic. Given the crisis and the online teaching processes, this approach aligns with the requirements of the institution where the research was conducted and with general didactic tools supported by the institution. Furthermore, the study primarily involved a non-invasive intervention of background music, which participants willingly engaged with, as evidenced by their support for its implementation (and written consent). No adverse effects or objections were reported by the students throughout the study. It is worth noting the absence of any experimental conditions that could potentially pose risks to the well-being of participants, emphasizing the notion of a safe and ethically conducted study. Overall, the positive response and lack of negative outcomes from both participants and the research process itself warrant the conclusion that no significant harms were associated with participation in this study and subsequent publication. Therefore, no significant harms were associated with participation in this research. It is important to note that the collected data are used at an aggregate level and anonymously.

Informed consent

All participants provided written informed consent.

Data available at: https://figshare.com/s/73b74b06ecb488cba7d4

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