

A Confirmatory Investigation into the Cognitive Effects of Background Music: Evidence from Sudoku-Based Experiments

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Abstract. The growing presence of background music in learning environments highlights the need to examine its influences on cognitive performance under varying task demands. Based on Zajonc's arousal theory, this study investigates how background music and task difficulty jointly influence cognitive performance and evaluates the relevance of this theory in student learning contexts. Accordingly, a 2×2 mixed experimental design was conducted with forty high school AP Psychology students, incorporating two environmental conditions, background music and silence, and two task difficulty levels, simple and complex Sudoku tasks. Participants solved low-load 4×4 Sudoku puzzles and high-load 9×9 Sudoku puzzles under both conditions, with completion time and errors recorded as performance measures. The results indicate that background music enhances simple-task performance by reducing completion time ($M = 55.50$ vs. 78.35) and errors (0.15 vs. 0.25). Nevertheless, it impairs complex-task performance by increasing completion time ($M = 542.45$ vs. 410.95) and errors ($M = 7.30$ vs. 3.65). Thus, the effects of background music depend on task demands. In Zajonc's arousal theory, music-induced arousal can enhance simple task performance by strengthening dominant responses, while excessive arousal may interfere with the controlled processing required for complex tasks.

Keywords: Background music, Arousal theory, Cognitive performance, Task difficulty, Mixed-design experiment

1. Introduction

With background music becoming increasingly prevalent in learning environments, many students use auditory stimulation as a means of supporting concentration and task efficiency [1]. Previous research has explored the relationship between background music and cognitive performance, thus showing that music can influence attention, arousal, and information processing; however, findings remain inconsistent, as background music appears to enhance performance in some situations while causing distraction in others [2, 3]. Zajonc's arousal theory explains these differences by suggesting that arousal enhances dominant responses but may disrupt controlled processing [4]. Although widely applied in social facilitation, this theory remains less explored in individual cognitive tasks

with auditory stimuli. In particular, insufficient attention has been given to how task difficulty may interact with background music to affect performance outcomes. This study explores the interactive effects of background music and task difficulty on cognitive performance among 40 high school AP Psychology students using a 2×2 mixed experimental design, in which participants complete simple 4×4 and complex 9×9 Sudoku tasks with or without background music, with completion time and error frequency recorded as performance measures. It is hypothesized that background music and task difficulty interact to affect cognitive performance, with music facilitating simple tasks but impairing complex tasks. By examining how auditory stimulation interacts with cognitive demands, it extends the application of arousal theory to learning contexts and provides practical implications for creating effective study environments, suggesting that background music may be beneficial for routine tasks while quiet conditions may better support complex cognitive activities.

2. Method

2.1. Experimental design

This study uses a 2×2 mixed experimental design to examine the effects of music environment and task difficulty on cognitive performance. In particular, music condition acts as the between-subjects independent variable, while task difficulty serves as the within-subjects independent variable. The music condition consists of two levels: the background music group, in which participants complete all tasks while continuously listening to soft, lyric-free instrumental music, and the silent group, in which participants complete all tasks in a quiet environment without auditory stimuli. Meanwhile, task difficulty is manipulated through Sudoku complexity, with the low-difficulty condition using 4×4 Sudoku puzzles representing low cognitive load tasks and the high-difficulty condition using standard 9×9 Sudoku puzzles representing high cognitive load tasks. The dependent variables are task completion time (measured in seconds) and error count, defined as the number of incorrectly filled digits compared with the standard answers [4].

2.2. Participants

This study involves forty high school AP Psychology students who participate in the experiment and are randomly assigned equally to the music group ($n=20$) and the silent group ($n=20$). At the same time, all participants have mastered fundamental Sudoku rules and demonstrate comparable academic achievement within the cohort. Moreover, exclusion criteria include hearing impairment and extreme sensitivity to background music. In terms of ethical considerations, participation is voluntary, with written informed consent obtained before formal testing. Participants are informed that they can withdraw from the experiment at any stage without adverse consequences.

2.3. Materials

This study uses two versions of Sudoku puzzles to measure cognitive performance. The simple 4×4 Sudoku requires basic pattern recognition and rule implementation, whereas the complex standard 9×9 Sudoku requires multi-step logical deduction and sustained focused attention. For auditory stimulus manipulation, uniform soft, lyric-free instrumental music is selected to minimize linguistic interference. The same audio track is played at a fixed and consistent volume for all participants in the music group. Task completion time is recorded using a digital stopwatch, and incorrect entries are identified using standard answer keys.

2.4. Procedure

The experiment employs a standardized procedure to maintain consistent testing conditions for all participants. Specifically, the testing is conducted individually in an isolated, controlled laboratory environment for all participants. Before testing, participants receive written instructions on Sudoku rules and the procedure. In the testing phase, participants in the music group listen to background music continuously, while those in the silent group complete all puzzles without audio playback. The order of Sudoku tasks is counterbalanced across participants to control for sequence effects, with half completing simple Sudoku first and the other half completing complex Sudoku first. A standardized 60-second rest interval is maintained between the two puzzle tasks. After each Sudoku task, researchers record completion time and total error count. The collected behavioral data are then imported into Microsoft Excel for subsequent statistical analysis.

3. Results

3.1. Effects of background music and task difficulty on cognitive performance

Performance outcomes under different music conditions are compared across two task difficulty levels. Raw behavioral data from all participants are shown in Table 1, while descriptive statistics of completion time and error counts for simple and complex Sudoku tasks are presented in Table 2.

Table 1. Raw data of participants' performance across experimental conditions

Participant_ID	Group	Order	Simple_Time_sec	Simple_Errors	Complex_Time_sec	Complex_Errors
1	Music	Simple_First	52	0	511	7
2	Music	Simple_First	48	0	560	8
3	Music	Simple_First	63	0	480	5
4	Music	Simple_First	58	0	596	9
5	Music	Simple_First	45	0	530	7
6	Music	Simple_First	55	0	515	6
7	Music	Simple_First	61	0	620	10
8	Music	Simple_First	50	2	461	5
9	Music	Simple_First	59	0	550	8
10	Music	Simple_First	67	1	582	9
11	Music	Complex_First	49	0	495	6
12	Music	Complex_First	54	0	610	7
13	Music	Complex_First	60	0	505	8

Table 1. (continued)

14	Music	Complex_First	46	0	525	5
15	Music	Complex_First	57	0	585	9
16	Music	Complex_First	62	0	503	6
17	Music	Complex_First	51	0	604	10
18	Music	Complex_First	56	0	543	7
19	Music	Complex_First	64	0	578	8
20	Music	Complex_First	53	0	496	6
21	No_Music	Simple_First	75	0	382	3
22	No_Music	Simple_First	82	0	422	4
23	No_Music	Simple_First	70	0	390	2
24	No_Music	Simple_First	90	0	452	5
25	No_Music	Simple_First	68	2	361	3
26	No_Music	Simple_First	78	0	414	2
27	No_Music	Simple_First	85	0	473	6
28	No_Music	Simple_First	72	0	358	3
29	No_Music	Simple_First	80	0	430	4
30	No_Music	Simple_First	88	0	441	5
31	No_Music	Complex_First	66	0	370	2
32	No_Music	Complex_First	86	2	461	4
33	No_Music	Complex_First	74	0	385	3
34	No_Music	Complex_First	79	0	415	5
35	No_Music	Complex_First	83	0	428	4
36	No_Music	Complex_First	71	0	361	2
37	No_Music	Complex_First	89	1	447	6
38	No_Music	Complex_First	77	0	402	3
39	No_Music	Complex_First	73	0	395	4

Table 1. (continued)

40	No_Music	Complex_First	81	0	432	3
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Table 2. Descriptive statistics of cognitive performance by music condition

Task Condition	Measure	Music Group	No-Music Group
Simple Sudoku	Completion Time	M = 55.50, SD = 6.26	M = 78.35, SD = 7.16
Simple Sudoku	Errors	M = 0.15, SD = 0.49	M = 0.25, SD = 0.64
Complex Sudoku	Completion Time	M = 542.45, SD = 47.21	M = 410.95, SD = 34.98
Complex Sudoku	Errors	M = 7.30, SD = 1.59	M = 3.65, SD = 1.27

The results show different effects of background music across task difficulty levels. For simple Sudoku tasks, participants in the music group completed puzzles faster than those in the silent group, with a lower mean completion time (M = 55.50s vs. 78.35s) and fewer errors (M = 0.15 vs. 0.25). In contrast, for complex Sudoku tasks, participants in the music group showed longer completion times (M = 542.45s vs. 410.95s) and higher error counts (M = 7.30 vs. 3.65) compared with the silent group.

3.2. Performance differences on simple Sudoku tasks under different audio conditions

Performance differences between the music and silent groups on simple Sudoku tasks are presented in Table 3. Participants in the music group completed simple Sudoku tasks faster than those in the silent group, with a lower mean completion time (M = 55.50s vs. 78.35s). Error counts were low in both groups, with the music group showing a slightly lower mean error count (M = 0.15) compared with the silent group (M = 0.25).

Table 3. Mean differences in simple Sudoku performance between music and silent groups

Measure	Music Group Mean	No-Music Group Mean	Difference
Completion Time (s)	55.50	78.35	-22.85
Errors	0.15	0.25	-0.10

3.3. Performance differences on complex Sudoku tasks under different audio conditions

For complex Sudoku tasks, performance differences between the music and silent groups are shown in Table 4. Participants in the music group required a longer mean completion time than those in the silent group (M = 542.45s vs. 410.95s). The music group also showed a higher mean error count compared with the silent group (M = 7.30 vs. 3.65).

Table 4. Mean differences in complex Sudoku performance between music and silent groups

Measure	Music Group Mean	No-Music Group Mean	Difference
Completion Time (s)	542.45	410.95	+131.50
Errors	7.30	3.65	+3.65

4. Discussion

4.1. Divergent effects of background music across task difficulty levels

The findings are consistent with Zajonc's arousal theory, suggesting that the effects of background music vary depending on task demands [4]. As an environmental stimulus, background music may increase arousal levels and influence cognitive performance differently across tasks [2, 5].

For low-load 4×4 simple Sudoku tasks, performance relies more on automatic and well-practiced responses. Moderate arousal induced by background music may facilitate these dominant responses, leading to faster completion times without increasing error rates [4]. In contrast, high-load 9×9 complex Sudoku tasks require controlled logical processing and sustained attention. Higher arousal levels associated with background music may interfere with these cognitive processes, resulting in longer completion times and increased error counts. These results support the application of Zajonc's arousal theory in explaining how arousal influences performance under different task conditions.

4.2. Practical educational implications of background music usage

This study extends the practical application of arousal theory from traditional social facilitation contexts to individual learning environments. Furthermore, the findings indicate that the effect of background music is not uniformly beneficial or harmful; instead, its effect relies on the interaction between environmental stimulation and task demands [6]. This suggests that learning environments should be designed according to the cognitive requirements of specific tasks rather than applying background music as a universal strategy.

In educational settings, background music may support routine learning tasks by promoting efficient performance under moderate arousal [7, 8]. Yet, complex tasks requiring higher cognitive control may benefit from reduced auditory stimulation to maintain focused processing [9]. Thus, the use of background music should depend on task demands, with learning environments adjusted to cognitive load.

4.3. Limitations of background music research and future directions

This study has several methodological limitations related to auditory stimulus selection, task design, and sample characteristics, which should be considered in future research. Regarding the auditory stimulus, only one type of lyric-free soft instrumental music was utilized, limiting the investigation of how specific music characteristics influence cognitive performance. In particular, variations in tempo, rhythm, volume, genre, and individual preference were not examined in the current design [10]. Future research could explore how different musical features and individual differences jointly affect the relationship between background audio and cognitive performance.

In addition to the limitation of music selection, the low difficulty of the 4×4 Sudoku task may have created a ceiling effect among experienced participants, reducing variability in performance across conditions. Future studies could adopt tasks with a wider range of difficulty levels or more balanced cognitive demands to better examine how arousal interacts with task requirements. Additionally, the current sample consists only of forty high school students, which may limit the generalizability of the findings. Future research could include participants from different age groups and educational backgrounds to explore whether the effects of background music vary across populations.

5. Conclusion

Based on behavioral data from 40 high school students completing simple and complex Sudoku tasks, this study demonstrates that the effects of background music on cognitive performance vary according to task difficulty, supporting the application of Zajonc's arousal theory in individual learning contexts. Specifically, background music has opposite effects: it improves simple-task speed with similar accuracy but impairs complex-task performance by increasing time and errors. These findings extend the application of arousal theory to cognitive learning environments by highlighting the interaction between environmental stimulation and task demands. The results suggest that background music may support routine and familiar learning activities, while quieter environments may better facilitate complex tasks requiring intensive cognitive processing. Future research can further examine how music characteristics, individual differences, and task types interact to influence cognitive performance in educational settings.

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