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# Effects of Multimodal Stimuli on Students' Attentional Control During task Switching

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**Abstract.** The purpose of this study was to investigate the effect of attention control under the influence of auditory stimuli (music type: excited, depressing, soothing, cheerful) and tactile stimuli (vibration type: low frequency, high frequency) in different subjects, so as to provide guidance to adjust the design of different stimuli and their combinations in students' learning space.We selected 24 college students (12 males and 12 females) who were physically and mentally healthy. Subjects were asked to concentrate on the game and attention test activities before and after the task switching process under 8 different stimulus conditions, and the eye tracking task performance and eye tracking data after the task switching were obtained. The attention control effect was obtained through the analysis of task switching paradigm, attention percentage calculation and quantitative eye tracking data. Finally, the effects of different auditory tactile stimuli on participants' attention control were compared.The combination of different auditory and tactile stimuli had a significant effect on the attention level after task switching, with the attention level being the lowest in the combination of suppressed music and high-frequency vibration, and the highest in the combination of cheerful music and low-frequency vibration. These results provide important data for elucidating the impact of multimodal stimuli on attention control in task switching.

**Keywords:** Multi-modal stimulation, attention control, task switching, learning space, students.

## 1. Introduction

Nowadays, with the development of online networks and personal terminals, multitasking is becoming a common phenomenon[1], and most students face problems with the allocation of attention as well as the inability to maintain concentration (the degree of attention retention) in a multitasking work-learning environment . Attention is a fundamental cognitive concept that is essential for higher order cognition and all aspects of real world activities. Students' exposure to information technology and multitasking in their personal lives, schools and workplaces can pose challenges to their attention[2]. These distraction-inducing multitasking environments can negatively affect both their work and learning[3]. For example, students allocate their attention when using handheld devices. Both sending and receiving messages from social networks can affect their performance[4]. Therefore we need to improve the effectiveness of their attentional control so that students can improve and re-improve their attentional level when switching tasks and restarting the learning process, helping them to optimize their performance and effectiveness in work and learning.

The link between the learning environment and learning activities has been demonstrated in several studies, and Beard and Wilson[5] developed the Learning Cryptograph Lock (LCL), which emphasizes the importance of linking the learning environment as the “place” of learning with specific learning activities as the “content” of learning. Amalan Sigmund Kawshik's team found that classrooms with standard windows provided better lighting, which improved student attention. This highlights the optimal lighting conditions for maintaining student engagement[6]. Research by Somerville and Collins[7] demonstrated the importance of comfortable, reconfigurable furniture in learning spaces in terms of functionality, among other things. Many of the studies mentioned above have emphasized the impact of the learning environment on students. Learning spaces such as study

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desks and library corners are the vehicles of the learning work environment and are the places that have the most direct impact on student learning.

Attention is one of the most fundamental features of cognitive performance and is also the most essential element that plays an important role in other mental tasks[8,9]. Maintaining attention in a multitasking environment is a prerequisite for improving the performance of young people in learning and work tasks. Some scholars have found that stimulation does have positive effects in enhancing users' attention as well as task performance[10]. In addition to this, several studies have shown that the use of stimuli in attention training may be effective. In a study of ADHD children performing tasks in a virtual reality environment, scholar Hong showed that giving additional and continuous stimuli resulted in higher task performance. This was due to the fact that they were able to maintain their interest in the task when given sustained and additional stimuli [11]. Sustained and extra stimuli are also often used in attention training. In addition, a large number of studies in the literature have pointed out that these stimuli help in self-regulation and control of attention and enhance attentional awareness, as it provides human behavior with functional assistance in self-regulation and learning[12,13].

Multimodal stimuli are one of the sources of influences on attention, but as discussed by scholar Hutmacher, there is a tendency for attention research to tend to place more emphasis on and study the effects of visual stimuli on attention[14]. It has been argued that vision is more socially and culturally dominant than the other senses[15]. However, the other senses are not to be ignored and can also have an impact on attention; one study investigated the effects of different sensory modalities on cognitive abilities and found that cross-modal stimuli (visual-auditory) performed better in a multisensory task compared to a unimodal condition[16]. Furthermore, this study showed that awareness of unexpected modalities in a task can improve performance, suggesting that attentional loss can be mitigated by manipulating attentional sets with different stimulus modalities[17]. These findings suggest that multimodal stimuli can enhance attention and cognition in a variety of situations. Visual and auditory combinations enhance attention and facilitate visual attentional processing more than unimodal feedback[18].Pomerleau et al. showed that simultaneously presented visual-auditory feedback enhanced attention[19]. Simultaneous visual and auditory bimodal feedback increases the perceived salience of the target[20], making it more salient in visual judgment tasks[21] and triggering bottom-up feedback-driven processing.

In summary, while there have been many studies exploring the effects of stimuli on attention including learning and training performance. However, different modal combinations of feedback on attention level stimuli have not for the current learning environment where students face increasing multitasking. By exploring the effects of using different stimulus combinations on students' attention during task switching, a more comprehensive understanding of the relationship between multimodal stimulus combinations on attention and students' task-switching performance can be obtained.

## 2. Materials and Methods

In this study, we first selected combinations of typical auditory and tactile stimuli with varying parameters as variables. Subsequently, we employed a task-switching paradigm to assess the effectiveness of participants' attention control. Simultaneously, eye movement signals were collected using eye-tracking devices. The analysis was conducted by integrating task performance with eye movement data. Finally, parameters related to saccades, blinks, and pupil size were calculated and analyzed using SPSS to evaluate the impact of auditory and tactile stimuli on attention control effectiveness. Given that the obtained data did not follow a normal distribution, we utilized the Generalized Linear Model (GLM) approach for analysis[22].

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**2.1 Experimental Subjects**

In order to ensure the accuracy of the experiment and the generalizability of the results, 24 physically and mentally healthy postgraduate students (12 males and 12 females) were selected as subjects. The subjects were 21-25 years old (average 23 years old).

We familiarized the subjects with the experimental environment and the experimental process before they arrived at the laboratory to start the experiment, in order to avoid the excitement caused by the unfamiliar environment. During the experiment, the real learning space as well as the environment was simulated as much as possible.

2.1.1 Experimental materials

We used a subjective online questionnaire to categorize music into 4 types, including depressing, soothing, exciting, and joyful. Each type of auditory stimulus was carefully screened and parameterized to intercept 10s of content from complete pure music. The soothing auditory stimulus was “A NEW DAY”, for example, with a moderate dynamic range as shown, and the overall volume was kept at a medium level, smooth and steady, which perfectly fit the core characteristics of soothing music.The depressing auditory stimulus used the pure music of Innocent. The dynamic range was small as shown, and its low tempo reinforced the negative emotional effect of the music. He's a Pirate” was chosen for the exciting auditory stimulus, with a larger dynamic range as shown. It has a strong rhythm, bright major key and dramatic melody. The upbeat category is represented by “Cat Cultivation March” with a moderate dynamic range as shown. It has a fast tempo, bright harmonies, and a light melody.

In this experiment, vibration was selected as the medium for tactile stimulation, and the vibrations were categorized into high-frequency and low-frequency based on differences in frequency. The high-frequency vibration was set at 50 Hz, while the low-frequency vibration was set at 20 Hz. The intensity of the vibration stimuli was uniformly set at 0.5 $m/s^2$ (vibration acceleration) to ensure that participants could clearly perceive the stimuli without experiencing significant discomfort. The tactile vibrations were delivered through a tactile vibrator in the form of continuous pulses, with a duration of 10 seconds.

2.1.2 Task setup

(1)Non-Learning Tasks

Leisure task set to 2048 The game is played on a 4x4 grid, where each cell can be empty or contain a power of 2, starting with a value of 2 or 4 randomly assigned to two cells.(Fig. 1) The player slides blocks in the four possible directions (up, down, left, right) to combine blocks of the same number, with the goal of creating blocks with the value 2048. The goal was to combine blocks to obtain the highest possible block value while filling the grid with as few empty cells as possible. In this task, the subject's goal was to synthesize the number 128.

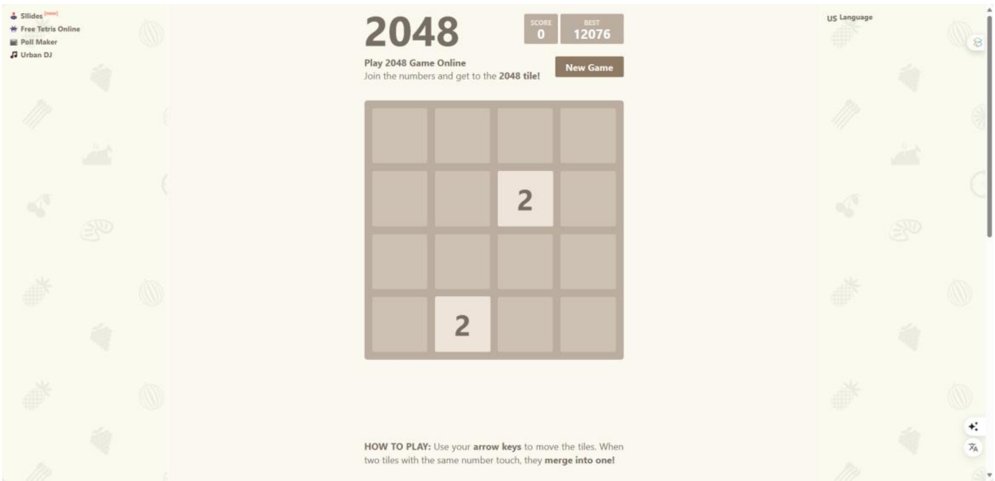


Fig. 1 Non-Learning Tasks(source:https://2048game.com/)

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(2)Visual search task

In the experiment, a total of nine pictures will be displayed on the monitor with ten rows and ten columns 10*10 of 100 non-repeating numbers, four of which will have repetitions, and each of the repetitions will be repeated five times. That is, there will be a total of 20 numbers with repetitions and they will randomly overlay the non-repeating numbers.(Fig. 2) These pictures would be displayed on the monitor for 120 s in each set of experiments. before the actual experiment, a set of training trials was conducted to help subjects adapt and enter the attentional state.

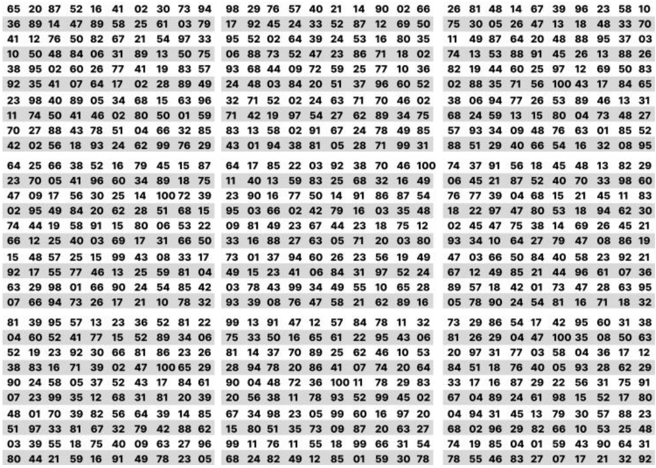

Fig. 2 Visual search task(source:made by the author)

### 2.2 Experimental Apparatus

There was an air conditioner in the lab to ensure the environmental parameters such as temperature and humidity during the experiment. We set the temperature at 25 degrees Celsius and the relative humidity at 40%. The lab was well insulated with soundproofing materials and noise-canceling headphones, REDMI BUDS 3 pro, were worn to ensure that the subjects were not disturbed by external noise during the experiments. The noise level was controlled at 25 dB, and the working plane used in the experiments was similar in size to the daily working plane, 1200 mm long and 800 mm wide, with non-experimental objects removed. The recreational task and the visual search task were performed sitting in front of an HP screen with a resolution of 1920*1080 pixels. Performance on the visual search task was utilized to measure attention levels in the strategic outcome assessment.

A Tobii X2-60 desktop eye-tracker was used in the experiment to collect eye-movement data from the subjects:(1) Saccadic Amplitude ;(2) Pupilleft and pupilright ; (3) first fixation duration ; (4) Total fixation durationAttention level was measured using two parameters from the visual search task: (1) visual search correctness; (2) visual search task completion time.

Fig. 3 Experimental scene (source: made by the author)

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**2.3 Experimental Procedure**

We set the validity of the visual search task in such a way that subjects had to search for 2 min and find at least two duplicate numbers within 2 min. Participants were asked to remain focused during the visual search task or they would be asked to re-experiment. During the formal experiment, a total of ten sets of tasks were switched for the subjects, from a non-learning task to a learning task. A Latin-square design was conducted. It was ensured that each subject was subjected to different conditions in a different order so that the learning effects were evenly distributed across the conditions, thus canceling each other out.

Pre-experiments as well as the thesis review identified different types of music in the auditory stimuli as well as different vibration frequencies for the tactile stimuli. Noise-canceling headphones were used in the experiments to isolate the external auditory stimuli and provide a stable and silent external environment. Eight different stimulus combinations of auditory and tactile stimuli were simulated through the headphones and cushions on the seat and randomly assigned to the subjects.

The collected eye movement data were preprocessed as follows: firstly, the region of interest was delineated, and the valid eye movement data during the visual search task was filtered for each subject. Relevant data including eye jump, pupil diameter and gaze point time were exported.

And the collected scores of the visual search task were preprocessed. The performance of the visual search task was converted to the percentage of attention by the specific formula as follows.

$$accuracy = \frac{\mathrm{frn} * 100}{20}$$

$$\text{average\_search\_time} = \frac{\mathrm{tft}}{\mathrm{frn}}$$

$$\text{Attention (\%)} = \frac{\text{accuracy / 100} * 120}{\text{average\_search\_time}}$$

Frn is the total number of correct numbers found by the subjects in the time period

Tft is the total time it took the subject to find all the duplicate digits, not found in 120s.

## 3. Results

### 3.1 Analysis of Eye movement Data

3.1.1 Eye Jump Amplitude

Descriptive statistics of eye-beat amplitude are shown in Table 1.

Under the low-frequency tactile stimulation condition, the mean value of eye-beat amplitude was the highest for the cheerful type of auditory stimulation, M = 6.68, followed by the soothing type (M = 6.35), the agitated type (M = 6.16), and the depressing type (M = 5.88). This suggests that the upbeat type of auditory stimuli may have a positive effect on the learners' attentional control in the presence of low-frequency tactile stimuli. Comparison of the mean eye-beat amplitude of the control group without any stimuli (M=5.90) reveals that the depressing type had a negative effect on the students' attentional control, whereas all the other three types of auditory stimuli resulted in a better level of attentional control.

In the high-frequency tactile stimulus condition, the mean value of the cheerful type of auditory stimuli was likewise the highest, M=6.26, followed by the soothing type (M=5.94), the exciting type (M=5.71), and the depressing type (M=5.52). Compared to the low-frequency tactile stimulation condition, the effect of each auditory stimulus type on learners' eye-beat amplitude was reduced in the high-frequency tactile stimulation. However, the cheerful type of auditory stimuli still had relatively high mean values, indicating that its positive effect on learners' attentional control remained under high-frequency tactile stimulation. Comparison of the mean values of

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eye-beat amplitude in the control group without any stimuli (M=5.90) reveals that only the upbeat and soothing auditory stimuli had positive effects on students' attentional control under high-frequency tactile stimuli, while the agitated and depressed auditory stimuli produced side effects.

Comprehensive analysis of the data under both low-frequency and high-frequency tactile stimulation conditions revealed that the cheerful auditory stimuli exhibited higher mean values of eye-beat amplitude under both tactile stimulation conditions, suggesting that they had a general supportive effect on learners' attentional control and academic performance. In contrast, the depressing auditory stimuli showed lower mean values of eye-beat amplitude in both tactile stimulus conditions, even lower than that of the control group, suggesting that they had a detrimental effect on learners.

As shown in Table 2, the results analyzed by generalized linear modeling showed that the Wald Chi-Square of tactile stimulus was 6.392 with 1 degree of freedom, corresponding to a p-value of 0.011, which is lower than 0.05, indicating that tactile stimulus had a significant effect and main effect on the eye-beat data; and that the Wald Chi-Square of auditory stimulus was 12.695 with 3 degrees of freedom, corresponding to a p-value of 0.005, which is much lower than 0.05, which indicates that auditory stimuli have a very significant effect and main effect on the eye-beat data; however, the Wald Chi-Square for the interaction between tactile stimuli and auditory stimuli is 0.036, with a degree of freedom of 3, corresponding to a p-value of 0.998, which is much higher than 0.05, which indicates that there is no significant interaction between tactile stimuli and auditory stimuli, implying that the tactile stimuli and auditory stimuli on the eye-beat data effects are independent of each other and there is no significant synergistic or inhibitory effect between them.

Table 1.Descriptive statistics of saccade amplitude

| Tactile stimuliation | Auditory stimulation | M | SD |
|---|---|---|---|
| Low frequency | Soothing | 6.35 | 0.23 |
| | Repressive | 5.88 | 0.23 |
| | Agitated | 6.16 | 0.23 |
| | Cheerful type | 6.68 | 0.23 |
| high frequency | Soothing | 5.94 | 0.23 |
| | Repressive | 5.52 | 0.23 |
| | Agitated | 5.71 | 0.23 |
| | Cheerful type | 6.26 | 0.23 |
| Control group | | 5.90 | 0.23 |

Table 2. Generalized linear model of saccade amplitude

| | Interaction characteristics | Wald Chi-Square | DoF | *p* |
|---|---|---|---|---|
| saccade amplitude | Tactile stimuliation | 6.392 | 1 | 0.011* |
| | Auditory stimulation | 12.695 | 3 | 0.005** |
| | TS×AS | 0.036 | 3 | 0.998 |

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3.1.2 First Fixation Times

Descriptive statistics of first fixation times are shown in Table 3.

In the low-frequency haptic stimulation environment, the study data showed that the mean value of first fixation time induced by cheerful auditory stimuli was the lowest (M=0.11 s), followed by soothing (M=0.12 s), exciting (M=0.13 s), and depressing (M=0.15 s), in descending order. This phenomenon suggests that upbeat auditory stimuli in the context of low-frequency tactile stimuli have a positive effect on learners' attentional control. Compared to the control group without any stimulus intervention (M=0.15), all three auditory stimulus types, cheerful, soothing, and arousing, demonstrated some degree of positive modulation, whereas the depressing auditory stimulus had no effect.

Moving to the high-frequency tactile stimulus condition, the mean first fixation time for the agitated auditory stimulus soothing auditory stimulus was M = 0.14 s, for the repressed type M = 0.18 s, for the agitated type M = 0.10 s, and for the cheerful type M = 0.12 s. The average first fixation time for the agitated type was M = 0.14 s, for the repressed type M = 0.18 s, for the agitated type M = 0.10 s, and for the cheerful type M = 0.12 s. This suggests that in the context of high-frequency tactile stimuli, the arousing type of auditory stimuli was most effective for attentional control on attentional control. Compared to the low-frequency tactile stimulation context, the degree of influence of depressing, cheerful, and soothing auditory stimuli on first fixation time in the context of high-frequency tactile stimulation was attenuated, except for the arousing type of auditory stimulation which was not affected by the increase in vibratory frequency, but instead appeared to have a more significant enhancement. A re-comparison with the control group verified the possible detrimental effect of the depressing auditory stimuli on first fixation time under this condition.

The results of the analysis of the generalized linear model of first fixation time revealed the following key findings, as shown in Table 4: First, the main effect of auditory stimuli was significant (p=0.000), indicating that different types of auditory stimuli had a significant effect on learners' first fixation time. This result is consistent with the phenomenon observed in the analysis of descriptive statistics data, i.e., there is a difference in the effect of different types of auditory stimuli (soothing, depressing, exciting, and cheerful) on the learners' rate of attention fixation; second, the main effect of the tactile stimuli was not significant (p=0.053), suggesting that there may not be an effect on the first fixation time of the learners; most importantly, the tactile stimulus-auditory stimulus interaction was significant (p=0.015), indicating that the combination of tactile and auditory stimuli had a significant interaction effect on learners' first fixation time. Pairwise comparisons were made when there was an interaction effect between the two factors, and the results showed that: when the tactile stimulus was low-frequency, there was a significance between soothing auditory stimulus and depressing (p=0.015), and between depressing and exhilarating (p=0.002); when the tactile stimulus was high-frequency, there was a significance between soothing auditory stimulus and depressing (p=0.015), between soothing and exhilarating (p=0.003), and between depressing and exhilarating (p=0.003); and between depressing and exhilarating (p=0.003). type and arousing type (p=0.000), and depressing type and cheerful type (p=0.000) are significantly different from each other; facing the soothing (p=0.032) and depressing auditory stimuli (p=0.032), there is a significant difference in the effect of high-frequency versus low-frequency haptic stimuli on the first fixation time of the students, whereas the arousing (p=0.077) and cheerful (p=0.178) types of There was no significant difference between high and low frequencies.

Table 3. Descriptive statistics of the time of first fixation

| Tactile stimuliation | Auditory stimulation | M | SD |
|---|---|---|---|
| Low frequency | Soothing | 0.12 | 0.01 |

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| | | | |
|---|---|---|---|
| | Repressive | 0.15 | 0.01 |
| | Agitated | 0.13 | 0.01 |
| | Cheerful type | 0.11 | 0.01 |
| high frequency | Soothing | 0.14 | 0.01 |
| | Repressive | 0.18 | 0.01 |
| | Agitated | 0.10 | 0.01 |
| | Cheerful type | 0.12 | 0.01 |
| Control group | | 0.15 | 0.01 |

Table 4. Generalized linear model of first fixation time

| | Interaction characteristics | Wald Chi-Square | DoF | *p* |
|---|---|---|---|---|
| First Fixation Times | Tactile stimuliation | 3.753 | 1 | 0.053 |
| | Auditory stimulation | 33.018 | 3 | 0.000*** |
| | TS×AS | 10.418 | 3 | 0.015* |

3.1.3 Total Fixation Duration

The descriptive statistics for total fixation duration are shown in Table 5. The research findings indicate that, in a low-frequency tactile stimulation environment, different types of auditory stimuli have a significant impact on learners' total fixation duration. Specifically, total fixation duration significantly increased under cheerful auditory stimulation, with a mean of 67.18 seconds, whereas it significantly decreased under oppressive auditory stimulation, with a mean of only 55.85 seconds. This suggests that, in the context of low-frequency tactile stimulation, cheerful auditory stimuli may positively enhance learners' attention maintenance, while oppressive auditory stimuli may inhibit their attention sustainability to some extent. Similarly, under high-frequency tactile stimulation, cheerful auditory stimuli continued to exhibit a significant positive effect on total fixation duration, with a mean of 62.73 seconds. In contrast, total fixation duration under oppressive auditory stimuli remained the shortest, with a mean of only 48.29 seconds. This result aligns closely with the findings under low-frequency tactile stimulation, further validating the robust effect of cheerful auditory stimuli in enhancing learners' attention maintenance. Additionally, a comparison between low and high-frequency auditory stimuli revealed that intense auditory stimuli (low-frequency M=59.16, high-frequency M=51.32) showed a noticeable decline in mean total fixation duration as vibration frequency increased.

In the control group with no stimulus intervention, the mean total fixation duration was 60.74 seconds. This value was similar to those under soothing auditory stimuli in both low and high-frequency tactile stimulation conditions but significantly higher than the results under oppressive auditory stimuli. This indicates that low or high-frequency soothing auditory stimuli have no significant effect on improving learners' attention control, while oppressive stimuli may weaken it. Moreover, similar to oppressive auditory stimuli, the mean total fixation duration of intense auditory stimuli was lower than the control group under both low (M=59.16) and high-frequency (M=51.32) conditions, suggesting a potential inhibitory effect on attention control.

According to the generalized linear model data for total fixation duration, the main effects of both tactile and auditory stimuli on learners' total fixation duration were statistically significant, but their interaction effect did not reach statistical significance, as shown in Table 6. For tactile

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stimulation, the main effect was significant (p=0.010), indicating that different tactile stimulation conditions significantly influenced learners' total fixation duration. For auditory stimulation, the main effect was also significant (p<0.001), demonstrating that different types of auditory stimuli significantly affected learners' total fixation duration. However, the interaction effect between tactile and auditory stimuli was not significant (p=0.820), suggesting that the two may lack a significant synergistic or inhibitory effect on learners' total fixation duration.

Table 5. Descriptive statistics of total fixation time

| Tactile stimuliation | Auditory stimulation | M | SD |
|---|---|---|---|
| Low frequency | Soothing | 62.31 | 3.18 |
| | Repressive | 55.85 | 3.18 |
| | Agitated | 59.16 | 3.18 |
| | Cheerful type | 67.18 | 3.18 |
| high frequency | Soothing | 59.48 | 3.18 |
| | Repressive | 48.29 | 3.18 |
| | Agitated | 51.32 | 3.18 |
| | Cheerful type | 62.73 | 3.18 |
| Control group | | 60.74 | 3.18 |

Table 6. Generalized linear model of total fixation time

| | Interaction characteristics | Wald Chi-Square | DoF | *p* |
|---|---|---|---|---|
| Total Fixation Duration | Tactile stimuliation | 11.762 | 1 | 0.010* |
| | Auditory stimulation | 13.489 | 3 | 0.000** |
| | TS×AS | 0.005 | 3 | 0.820 |

### 3.1.4 Pupilleft and pupilright

This study conducted descriptive statistical analysis on learners' pupil diameter under different auditory and tactile stimulation conditions, as shown in Table 7. The data analysis results revealed that multimodal stimuli significantly affected learners' pupil diameter. Under low-frequency tactile stimulation, the average pupil diameter for the left eye under soothing auditory stimuli was 3.38, and the right eye was 3.51; under oppressive auditory stimuli, the left eye was 3.30, and the right eye was 3.35; under intense auditory stimuli, the left eye was 3.35, and the right eye was 3.44; and under cheerful auditory stimuli, the left eye was 3.44, and the right eye was 3.60. Under high-frequency tactile stimulation, the average pupil diameter for the left eye under soothing auditory stimuli was 3.29, and the right eye was 3.42; under oppressive auditory stimuli, the left eye was 3.21, and the right eye was 3.27; under intense auditory stimuli, the left eye was 3.26, and the right eye was 3.36; and under cheerful auditory stimuli, the left eye was 3.32, and the right eye was 3.48. In the control group with no stimulation, the average pupil diameter for the left eye was 3.22, and the right eye was 3.32.

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From the data, it can be observed that cheerful auditory stimuli caused an increase in pupil diameter under both low and high-frequency tactile stimulation conditions, suggesting that cheerful auditory stimuli may more effectively enhance learners' attention concentration. Additionally, compared to high-frequency tactile stimulation, low-frequency tactile stimulation with the four types of auditory stimuli resulted in relatively better attention control. Furthermore, under both low and high-frequency tactile stimulation, the pupil diameters of the left and right eyes under soothing, intense, and cheerful auditory stimuli were larger than those in the control group, while oppressive stimuli were smaller than the control group, indicating that oppressive auditory stimuli may have adverse effects, whereas the other three types of auditory stimuli can effectively improve attention control.

Through the generalized linear model analysis of pupil diameter, it was found that tactile stimulation had a significant effect on the first fixation time for both the left eye (p=0.001) and the right eye (p=0.019), and auditory stimulation also had a significant effect on the left eye (p=0.019) and the right eye (p=0.000), indicating that both modalities have main effects on pupil diameter, as shown in Table 8. However, the interaction effect between tactile and auditory stimuli did not reach statistical significance for the first fixation time of either the left eye (p=0.980) or the right eye (p=0.985).

Table 7. Descriptive statistics of pupil diameter size

| | Tactile stimulation | Auditory stimulation | M | SD |
|---|---|---|---|---|
| Pupilleft | Low frequency | Soothing | 3.38 | 0.04 |
| | | Repressive | 3.30 | 0.04 |
| | | Agitated | 3.35 | 0.04 |
| | | Cheerful type | 3.44 | 0.04 |
| | High frequency | Soothing | 3.29 | 0.04 |
| | | Repressive | 3.21 | 0.04 |
| | | Agitated | 3.26 | 0.04 |
| | | Cheerful type | 3.32 | 0.04 |
| | Control group | | 3.22 | 0.04 |
| pupilright | Low frequency | Soothing | 3.51 | 0.06 |
| | | Repressive | 3.35 | 0.06 |
| | | Agitated | 3.44 | 0.06 |
| | | Cheerful type | 3.60 | 0.06 |
| | High frequency | Soothing | 3.42 | 0.06 |
| | | Repressive | 3.27 | 0.06 |
| | | Agitated | 3.36 | 0.06 |
| | | Cheerful type | 3.48 | 0.06 |
| | Control group | | 3.32 | 0.06 |

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Table 8. A generalized linear model of pupil diameter size

| | | Interaction characteristics | Wald Chi-Square | DoF | *p* |
|---|---|---|---|---|---|
| Pupilleft and pupilright | Left eye | Tactile stimuliation | 10.775 | 1 | 0.001** |
| | | Auditory stimulation | 10.002 | 3 | 0.019* |
| | | TS×AS | 0.185 | 3 | 0.980 |
| | Right eye | Tactile stimuliation | 5.533 | 1 | 0.019* |
| | | Auditory stimulation | 18.475 | 3 | 0.000*** |
| | | TS×AS | 0.151 | 3 | 0.985 |

# 4. Discussion

This study, through a comprehensive analysis of eye-tracking data from visual search tasks and the attention level percentages of task performance, delves into the impact of tactile and auditory stimulus combinations on attention control and attention levels after task switching. Our findings not only confirm that tactile and auditory stimuli play a significant role in the differences in attention control during task switching but also provide critical data support for understanding the effects of these stimulus combinations on attention levels.

Specifically, we found that when tactile stimulation consisted of low-frequency vibrations paired with cheerful music as auditory stimulation, participants' attention levels peaked, and the effect on attention control was notably significant. This discovery aligns with previous research indicating that external stimuli, such as stimulating music, can enhance attention during learning, as demonstrated in studies by Mst. Marium Begum[23]. Similarly, in our study, stimulating music also enhanced attention, but the combination of low-frequency vibrations and cheerful music appeared to create a more conducive environment for attention focus. This environment likely optimizes attention performance by reducing distractions and promoting synchronization of neural activity.

Conversely, when tactile stimulation was high-frequency vibrations paired with oppressive music as auditory stimulation, participants' attention levels significantly declined, and attention control was poorer. This combination may create an environment detrimental to attention focus, where high-frequency vibrations could increase participants' anxiety, and oppressive music might further exacerbate this negative emotion, thereby impairing attention performance.

It is noteworthy that, although the performance of the visual search task and the mean attention percentage showed significant differences, they did not follow a normal distribution, and task performance did not entirely correlate with attention levels due to individual differences. Some participants achieved optimal search performance under intense auditory stimuli, while others did not perform the worst under oppressive auditory stimuli. Based on these differences, combined with post-experiment subjective questionnaires, we propose a hypothesis that when the rhythm of auditory stimuli preferred by individuals is paired with regular, non-distracting low-frequency vibrations, a certain interaction effect may occur. The outcome of this effect would likely be beneficial.

Although we observed that tactile and auditory stimuli significantly impact attention levels, the interaction effect between the two did not show significant differences in this study. This could be related to the complexity of the experimental design, sample size, and control of experimental conditions. Future research could further explore the interactions between these two types of stimuli and their effects in different contexts and individual variations.

Based on our findings, we propose a specific recommendation: when students switch from entertainment or leisure activities to learning tasks, appropriate low-frequency vibrations and

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cheerful music can be applied to help them quickly return to a learning state and maintain high attention levels. This strategy may be particularly suitable for learning scenarios requiring high concentration, such as exam preparation or solving complex problems.

Additionally, we noted that attention levels across all stimulus combinations were not entirely normally distributed. This suggests that different stimulus combinations may impact individuals differently, possibly due to factors such as neurophysiological characteristics, emotional states, and prior experiences. Future research could further investigate how these factors influence attention levels and how personalized interventions can optimize individual attention performance.

In summary, this study provides new perspectives on understanding the complex mechanisms of attention regulation by exploring the effects of tactile and auditory stimulus combinations on attention control and levels after task switching. Our findings not only offer valuable guidance for educational practices but also open new directions for future research.

## Conclusions

In summary, through the statistical analysis of eye-tracking data from visual tasks and the attention level percentages of task performance in this study, we confirmed that the differences in attention control after task switching are caused by the tactile and auditory stimuli during the switching process. These results provide significant data to clarify the impact of tactile and auditory stimulus combinations on attention control effectiveness and attention levels. This paper observed the effects of tactile stimuli (low-frequency and high-frequency vibrations) and auditory stimuli (gentle music, oppressive music, intense music, and cheerful music) combinations on attention control and levels after task switching. The results showed that participants exhibited the best attention levels and effective attention control when tactile stimulation was low-frequency vibrations paired with cheerful music. Conversely, when tactile stimulation was high-frequency vibrations paired with oppressive music, participants' attention levels were the lowest, and attention control was poor. The interaction effect between auditory and tactile stimuli did not show significant differences. We recommend that when students transition from entertainment or leisure activities back to learning tasks, corresponding low-frequency vibrations and cheerful music can be applied. Keeping vibrations and music at a relatively stable and rhythmic level helps students quickly return to a learning state and maintain their attention levels. Additionally, in personalized learning spaces, auditory and tactile customization can be incorporated to better adapt to the needs of different students.

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