SCHOLARLY REVIEW

# The Influence of Music, Short-term Memory, and Neurodivergence on Reading Comprehension

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## Author Biography

Maitreyi Bharath is a high school senior from San Jose, California, and is passionate about molecular biology and medical research. Along with research in biology, she is passionate about music, and hopes to pursue more research on the intersections of music and STEM fields. In her free time, you'll find her reading novels, laughing at old British sitcoms, or singing along to her favorite songs.


## Abstract

Background music has been shown in various studies to have many potential benefits for productivity and learning. In this paper, two studies were conducted to investigate the influence of different genres of background music on reading comprehension. One study focused on the effects of instrumental music, while the other study focused on the effects of vocal music and presence of neurodivergent conditions. The genres Pop and Rock were hypothesized to improve reading comprehension compared to silence, while Rap, Western Classical, Indian Classical, and Jazz were expected to impair reading comprehension. In both studies, background music, regardless of genre, had no significant effects on participants' reading comprehension. There were no significant differences in reading comprehension scores when participants were grouped by age, musical experience, or vocal versus instrumental music. There were significant differences in reading scores without background music between the neurodivergent and neurotypical groups. These differences disappeared after adding background music, indicating that background music impacted neurodivergent and neurotypical participants' reading abilities differently. Participants also completed a digit span forward task without background music to assess short-term memory capacity. Analysis of the reading and memory scores indicates that short-term memory is weakly linked to reading comprehension performance. Larger-scale studies are recommended to further validate these relationships between music and reading comprehension.


*Keywords: background music; musical genre; neurodivergence; reading comprehension; short-term memory; working memory; learning; cognitive task performance.*

## Introduction

Many believe listening to music boosts cognition (Hu et al., 2021; Kotsopoulou & Hallam, 2010). However, many studies have shown that music's effects on cognitive task performance and learning vary greatly (Du et al., 2020; Lehmann & Seufert, 2017; Mehr et al., 2013; Omeroglu & Li, 2022). Positive effects of music on cognition are typically attributed to a positive mood stimulated by music, also known as the arousal-and-mood hypothesis (Fabiny, 2015; Schellenberg, 2005; Schellenberg et al., 2007; Thompson et al., 2001; Zaccoletti et al., 2019; Amin et al., 2021; Holmes & Hallam, 2017; Rauscher et al., 1993). Disruptive effects on cognition are typically attributed to music's impact on working memory (WM) capacity, defined as the amount of information the brain can simultaneously retain and process (Gonzalez & Aiello, 2019; Thompson et al., 2011). Music, especially with lyrics, is thought to reduce WM capacity & resources available for reading comprehension tasks (Lehmann & Seufert, 2017; Sweller, 1998; Rey, 2012; Sanchez & Wiley, 2006). Individuals with low WM capacities are more significantly impacted by music than those with medium to high WM capacities (Beni et al., 1998; Carretti et al., 2005; Lehmann & Seufert, 2017; Palladino et al., 2001; Seigneuric & Ehrlich, 2005; Swanson & Berninger, 1995). Music also has mixed effects on short-term memory (STM).

Some studies define STM as the process of just temporarily retaining information and consider STM largely independent of reading comprehension, but STM also is sometimes considered interchangeable with WM (Prabhu et al., 2022; Miller, 2017; Musliu et al., 2017; Omeroglu & Li, 2022; Woo Ee & Kanachi, 2005; Wells et al., 2018). Music has been shown to improve task performance for people with neurodivergent conditions linked to reading comprehension performance and working memory, such as attention deficit hyperactivity disorder, obsessive-compulsive disorder, anxiety, and depression (Madjar et al., 2020; Martin-Moratinos et al., 2022; Quinn & Barton, 2024; Söderlund et al., 2010; Abdulah et al., 2018; Carpio De Los Pinos and Barroso López, 2021; Kim et al., 2024; Quevedo-Blasco et al., 2023; Quinn & Barton, 2024; Shirani Bidabadi & Mehryar, 2015; Truong et al., 2021; Hendren et al., 2018; Jacobson et al., 2011; Lee et al., 2018; Macdonald et al., 2021). This paper investigates the relationships between different genres of music, reading comprehension, STM, and neurodivergence. Based on each genre's complexity and potential effects on mood and WM capacity, pop and rock were hypothesized to improve reading comprehension performance, while jazz, rap, Western classical, and Indian Classical music were hypothesized to impair reading comprehension. Neurodivergent participants were hypothesized to benefit from background music in general.

## Methods

### IRB approval

Both studies were approved by a high school level Institutional Review Board, formed according to the Regeneron STS 2024 high school IRB guide (linked here). Scans of the IRB forms for both studies are available at the following hyperlinks: Study 1 IRB Form URL, Study 2 IRB Form URL

### Consent form & demographic form

Before the study, participants provided electronic signatures on an online consent form indicating their voluntary participation and right to withdraw from the experiment at any time. Minors were required to obtain parent signatures on the form. Study 2's consent form had an optional question allowing participants to voluntarily disclose any diagnosed neurodivergent conditions, including ADHD/ADD, depression, anxiety, autism, aphasia, auditory processing disorder, developmental language disorder, or dyslexia. Participant names were not collected as data and were only used to assign ID numbers to participants, enter participants into a gift card raffle, and identify participants that took part in both studies and had to be excluded from Study 2's dataset for the vocal versus instrumental music analysis. ID numbers allowed for anonymous matching of each participant's memory scores and reading scores. Participants also were requested to fill out an optional Google form with their assigned ID number, age, race/ethnicity, gender, and emails, and for Study 2 participants only, the number of years of musical experience rounded to the nearest whole number.

## Study 1 description

The study took place on Zoom with 29 middle and high school participants recruited by word-of-mouth. Participants' ID numbers were used to randomly group participants into one of six groups: Control (No Music), Jazz, Pop, Rock, Western classical, and Indian classical. Based on their group assignment, participants were provided links to a YouTube video that contained an instrumental playlist of their assigned genre (the control group did not receive any links). The playlists consisted of famous songs to ensure that each genre was well-represented and matched general assumptions of each genre's sound profile. Participants were requested to set their volume to half and to wear headphones.

Participants took a reading comprehension test while listening to their assigned playlist. The reading comprehension test consisted of two reading passages with twenty-one multiple choice reading comprehension questions taken from the College Board Official SAT Practice Test #1, which is freely available to the public on the official College Board website. Participants had 30 minutes to complete the test, administered via Google form. The raw percentage of correctly answered questions was taken as the reading score for each participant. Participants also took a modified digit span forward test to evaluate short-term memory and attention and serve as an additional control metric for the samples (Cullum, 1998; Holdnack, 2019; Raiford, Coalson, Saklofske, & Weiss, 2010; Seraji-Bzorgzad et al., 2019; Wells et al., 2018). No music was played in the background for the test. Participants were shown a Google slideshow of five series of single-digit numbers from 0 to 9 inclusive, generated with a random number generator. The length of the five series were 5 digits, 6 digits, 7 digits, 8 digits, and 9 digits, shown in that order, based on Miller's 1956 paper establishing that working memory capacity can hold up to seven items plus or minus two. The digits were shown one by one on individual slides at a rate of 50 slides per minute (based on a metronome), with alternating backgrounds of light blue and white to make slide-to-slide transitions clearer. Participants were given a Google form for their working memory test responses and informed about the potential repetition of digits. After being shown each digit series, participants were given 30 seconds to enter as much of the series as they could remember into the Google form. The accuracy of the participant answers for each series was then calculated as the correct digit value in the correct digit slot from left to right, with the leftmost digit always being the first digit in the series. Incorrect digits did not add or subtract from the accuracy percentages. The working memory accuracy data were then averaged together to give each participant a single memory score.

## Study 2 description

The experiment was conducted online via Zoom with 60 middle school, high school, and adult participants recruited through word-of-mouth. Participants were randomly assigned to one of six groups: Jazz, Pop, Rock, Western classical, Rap/Hip-hop, and Indian classical. Neurodivergent participants were assigned genres first to ensure even distribution across the six groups. Participants were then provided a link to a YouTube video containing a playlist of their assigned genre of music and requested to wear headphones. All playlists were of music with vocals.

Participants completed two ACT passages from the Official ACT website's free full-length practice test. Each passage had ten multiple-choice questions and a fifteen-minute time limit, and one passage was completed with background music while the other was completed in silence. Half of the participants did the reading task with background music first and silence second, while the other half did the reading task with silence first and music second. Participants submitted their answers on a Google form. Participants' raw scores on the reading passage with background music were labeled as "music scores". The raw scores on the reading passage without music were labeled as "silence scores". The difference between these scores was labeled as "music-minus-silence scores." Study 2's memory task was the same as the Study 1 memory task, only with different series of randomly generated numbers.

The playlists are linked in references for all genres except instrumental rock, instrumental jazz, and vocal jazz (Athena, 2023; BOAT, 2020; Home, 2020; sinpai, 2021; Today, 2015; Bhaskar, 2021; Melodies, 2023; Music, 2015), as these videos are no longer available on YouTube for unknown reasons.

### Data refinement & analysis

In Study 1, one participant's data was excluded due to a lack of memory score. In study 2, four participants' data was excluded due to a lack of memory score. Shapiro-Wilk tests were used to evaluate normality and Brown-Forsythe Tests were used to check the homogeneity of variance across genre groups (Supplementary Tables A1, A2, A3, A4, A5, A6). The significance level was set to 0.05.

## Results

### Effects of background music, overall and by genre

Study 1's five genre groups were consolidated into a single "music" subset. In both studies, reading scores with and without background music were compared using Mann-Whitney U tests. No significant differences were found (Table 1). Kruskal-Wallis tests were used to compare each genre group's reading and memory scores in both studies. No significant differences between genres were found (Table 2).

**Table 1**
Background music versus silence in reading comprehension task. Mann-Whitney U tests comparing reading task performance with and without music.

| Test | Comparison | Score Type(s) | Statistic | p-value |
|---|---|---|---|---|
| Mann-Whitney U test | Study 1 Music vs Silence | Reading scores | 38.5 | 0.550982 |
| Mann-Whitney U test | Study 1 Music vs Silence | Memory Scores | 52.0 | 0.818233 |
| Mann-Whitney U test | Study 2 Music vs silence | Music scores, Silence scores | 1484.0 | 0.619264 |

**Table 2**
Kruskal-Wallis tests comparing genres within each score type. Some groups were not normally distributed (Supplementary Tables A1, A2, A3, A4, A5, A6).

| Study # | Score Type | Statistic | p-value | Test Result |
|---|---|---|---|---|
| Study 1 | Reading Score | 2.897533 | 0.218155 | No Significant Difference Between Groups |
| Study 1 | Memory Score | 3.683767 | 0.218155 | No Significant Difference Between Groups |
| Study 2 | Music Score | 3.825193 | 0.218155 | No Significant Difference Between Groups |
| Study 2 | Silence Score | 1.780861 | 0.218155 | No Significant Difference Between Groups |
| Study 2 | Music-minus-silence | 1.756644 | 0.218155 | No Significant Difference Between Groups |
| Study 2 | Memory Score | 4.394637 | 0.218155 | No Significant Difference Between Groups |

### STM and reading comprehension

Ratio distributions were used to evaluate whether reading comprehension performance was independent of STM, as the ratio of two independent, zero-mean, normally distributed variables should be non-normal (Díaz-Francés & Rubio, 2012). In Study 1, reading and memory scores were normally distributed (Table 3) while the ratios of reading to memory scores (taken after both score types were recentered to have means of zero) were not normally distributed. However, when separated by genre group, the ratio distributions were normally distributed (Table 3). For Study 2, the ratio scores were derived by dividing the participants' music-minus-silence scores by their memory scores. Only Indian classical and Pop groups had normally distributed ratio distributions despite normally distributed reading and memory scores (Table 4).

**Table 3**
Study 1 distribution of ratios between reading and memory scores - Shapiro-Wilk results

| Genre | Test Statistic | p-value | Ratio distribution | Reading Score distribution | Memory Score distribution |
|---|---|---|---|---|---|
| All Ratios | 0.619421 | 2.489682e-07 | Not Normal | Normal | Normal |
| Indian Classical | 0.990789 | 0.982383 | Normal | Not Normal | Not Normal |
| Jazz | 0.936839 | 0.635146 | Normal | Normal | Normal |
| Control /No Music | 0.773731 | 0.062850 | Normal | Normal | Normal |
| Pop | 0.929250 | 0.591267 | Normal | Normal | Normal |
| Rock | 0.935693 | 0.635669 | Normal | Not Normal | Normal |
| Western Classical | 0.889924 | 0.356721 | Normal | Normal | Normal |

**Table 4**
Study 2 distribution of the ratio between reading and memory scores - Shapiro-Wilk results

| Genre | Test Statistic | p-value | Ratio distribution | Reading Score distribution | Memory Score distribution |
|---|---|---|---|---|---|
| All Ratios | 0.285427 | 5.043790e-15 | Not Normal | Normal | Not Normal |
| Indian Classical | 0.958505 | 0.752909 | Normal | Normal | Normal |
| Jazz | 0.695353 | 0.001995 | Not Normal | Not Normal | Normal |
| Pop | 0.973086 | 0.919758 | Normal | Normal | Normal |
| Rap | 0.535983 | 0.000017 | Not Normal | Normal | Not Normal |
| Rock | 0.576991 | 0.000085 | Not Normal | Normal | Normal |
| Western Classical | 0.810569 | 0.012959 | Not Normal | Normal | Normal |

## Role of neurodivergence in music-reading relationship

In Study 2, twelve participants voluntarily reported being diagnosed with neurodivergent conditions. All score types in Study 2 were compared between neurodivergent and neurotypical participants. Significant differences were only observed for silence scores (Table 5). Due to sample size constraints, individual genre group comparisons were not conducted.

**Table 5**
Difference between neurodivergent and neurotypical participant performance. Mann-Whitney U tests comparing scores between neurodivergent and neurotypical participants.

| Score Type | Statistic | p-value | Neurodivergent Median | Neurotypical Median |
|---|---|---|---|---|
| Music scores | 296.0 | 0.520877 | 0.9 | 0.8 |
| Silence scores | 360.5 | 0.049328 | 0.95 | 0.8 |
| Music-minus-silence scores | 198.0 | 0.182797 | -0.05 | 0.0 |
| Memory score | 266.5 | 0.968120 | 0.818050 | 0.7994 |

## Vocal versus instrumental music

Instrumental music was used in Study 1, and vocal music was used in Study 2. The genre groups in each study were consolidated into two datasets: vocal reading scores and instrumental reading scores. Participants who took part in both studies were excluded to ensure these two datasets were independent. Only scores from the reading task with background music were compared for each genre, so Study 1's control group was excluded. None of the genre groups in Study 1 matched Study 2's rap group, so the rap group was also excluded.

Since neither dataset was normally distributed (Supplementary Table A8), a Mann-Whitney U test was used to compare these values between the studies. No significant differences were found between the vocal reading scores and instrumental reading scores, both in full dataset comparisons and by-genre comparisons (Table 6). Memory scores were also compared by genre, and no significant differences were found between genre groups (Table 7).

**Table 6**
Reading score comparisons between vocal and instrumental music groups - Mann-Whitney U Results. Some groups were not normally distributed (Supplementary Tables A1, A2, A3, A4, A5, A6).

| Group | Statistic | p-value | Test Result |
|---|---|---|---|
| Overall Reading Scores | 452.5 | 0.706171 | No Significant Difference Between Groups |
| Indian Classical | 21.0 | 0.663621 | No Significant Difference Between Groups |
| Jazz | 17.0 | 0.712115 | No Significant Difference Between Groups |
| Western Classical | 28.0 | 0.758626 | No Significant Difference Between Groups |
| Pop | 19.5 | 0.459019 | No Significant Difference Between Groups |
| Rock | 14.0 | 0.414266 | No Significant Difference Between Groups |

**Table 7**
Memory score comparisons between vocal and instrumental music groups - Mann-Whitney U Test Results. Participants in the Study 2 Rap and Study 1 Control group were removed as these groups were not present in both Study 1 and Study 2. Some groups were not normally distributed (Supplementary Tables A1, A2, A3, A4, A5, A6).

| Group | Statistic | p-value | Test Result |
|---|---|---|---|
| Overall Reading Scores | 398.0 | 0.258255 | No Significant Difference Between Groups |
| Indian Classical | 32.0 | 0.439560 | No Significant Difference Between Groups |
| Jazz | 17.0 | 0.648485 | No Significant Difference Between Groups |
| Western Classical | 22.0 | 0.759254 | No Significant Difference Between Groups |
| Pop | 9.0 | 0.329004 | No Significant Difference Between Groups |
| Rock | 6.0 | 0.073530 | No Significant Difference Between Groups |

## Musical experience

In Study 2, participants had the option to report how many years of musical training or experience they'd received. Four participants did not report their musical training and were excluded from this comparison. Based on the scatterplot of the number of years of experience (Supplementary Figure A2), participants were grouped into three subsets: 0 to 5 years, 6 to 10 years, and more than 10 years of experience. As some of the groups in each subset had non-normal distributions (Supplementary Table A10), Kruskal-Wallis tests were run to compare music scores, silence scores, music-minus-silence scores, and memory scores between the three subsets. No significant differences were found (Table 8). Genre-by-genre comparisons were not made as some subsets did not have all six genres.

**Table 8**
Kruskal-Wallis test results comparing different groups separated by years of musical experience - Mann-Whitney U test results.

| Score Type | Statistic | p-value | Test Result |
|---|---|---|---|
| Music scores | 0.565971 | 0.753531 | No Difference Between Groups |
| Silence scores | 1.707781 | 0.425755 | No Difference Between Groups |
| Music-minus-silence scores | 1.690354 | 0.429481 | No Difference Between Groups |
| Memory score | 0.692665 | 0.707277 | No Difference Between Groups |

## Effect of age on music-reading relationship

In study 1, participants aged twelve to fourteen were compared to participants aged fifteen to eighteen. Reading scores and memory scores in both age groups were normally distributed (Supplementary Table A11), but sample sizes were unequal, so Mann-Whitney tests were used to compare each score type between age groups. No significant differences were found between age groups for either score type (Table 9).

**Table 9**
Study 1 Comparison between age groups: Mann-Whitney U test results.

| Score Type | Statistic | p-value | Test Result |
|---|---|---|---|
| Reading scores | 46.0 | 0.270555 | No Difference Between Groups |
| Memory score | 98.0 | 0.077748 | No Difference Between Groups |

In study 2, participants were split into three groups: twelve to fourteen, fifteen to eighteen, and nineteen and older. These groups were organized to mimic typical middle school, high school, and post-high school age groups. As some groups were not normally distributed (Supplementary Table A12), a Kruskal-Wallis test was used to compare each score type between age groups. No significant differences were found between age groups for any of the score types (Table 10).

**Table 10**
Study 2 Comparison between age groups: Kruskal-Wallis test results.

| Score Type | Statistic | p-value | Test Result |
|---|---|---|---|
| Music scores | 0.879546 | 0.644182 | No Difference Between Groups |
| Silence scores | 2.332579 | 0.311521 | No Difference Between Groups |
| Music-minus-silence scores | 5.128004 | 0.076996 | No Difference Between Groups |
| Memory score | 1.034515 | 0.596153 | No Difference Between Groups |

## Discussion

### Background music did not significantly impact reading comprehension scores

There was no difference between reading comprehension scores with background music and reading comprehension scores without background music. This indicates that background music in general does not significantly impact reading comprehension. When reading performance was compared by genre, there were no significant differences between genre groups in reading task performance. Since genres were randomly assigned and preference for genres was not considered, this indicates no specific genre of music has any inherent impact on reading comprehension.

### Presence of lyrics in music did not affect reading task performance differently from instrumental music

Based on previous literature, vocal music was expected to impair reading comprehension performance compared to instrumental music due to overloading of the phonological loop, particularly for the more complex or word-heavy genres like Jazz, Western Classical, Indian Classical, and Rap. However, there was no significant difference between the use of vocal music or instrumental music for the scores from the reading task with background music. Some considerations could be whether a language barrier had any impact — while pop, rock, rap, and jazz vocal music involve English lyrics, Indian classical music, and Western classical music mostly have non-English lyrics. Familiarity with any songs or language of the lyrics may have impacted how much information the participants were processing along with their reading task.

### Background music negatively impacted neurodivergent participants' reading performance

There were significant differences in the silence scores for neurodivergent and neurotypical scores (p-value of 0.0493), but no significant differences in music scores, memory scores, or music-minus-silence scores (Table 5 New). The median of the silence scores was higher in the neurodivergent group (0.95) than in the neurotypical group (0.8), while the music-minus-silence scores had a median of -0.05 for neurodivergent participants and median of 0.0 for the neurotypical participants. This indicates that music slightly impaired reading comprehension performance for neurodivergent participants, which made their music scores more like the neurotypical group's scores. The lack of significance in the music-minus-silence scores indicates that the impairment in performance may have been relatively small for each participant, but in the context of the neurodivergent group, the slight impairments were consistent enough to make the music scores of neurodivergent and neurotypical participants similar. Overall, music had different impacts on reading comprehension for neurodivergent participants and neurotypical participants.

### STM and reading task performance with background music are not always independent

Analysis of the ratio distributions showed that the overall set of reading scores and memory scores were independent for Study 1. However, when separated by genre group, the ratio distributions for the jazz, pop, control, and Western classical groups indicated that the reading and memory scores within these smaller groups may not have been independent. Since these effects seem to cancel out in the overall dataset for reading scores and memory scores, each genre may have had different effects on the relationship between STM and reading comprehension. Study 2's music-minus-silence scores allowed for an analysis of whether changes in reading scores caused by the presence of music were independent of participants' STM. The Indian classical and Pop groups both showed normal distributions for all three of the music-minus-silence scores, memory scores, and ratios, indicating that any changes in reading score caused by the presence of these genres of lyrical background music may not have been independent of the participants' STM.

### Factors to consider for future research

Any differences in scores caused by personal familiarity or preferences for certain genres of music were controlled for via random assignment of genres in both studies. Further research could focus on the potential effects of listening to preferred or familiar genres of music on reading comprehension or disliked or unfamiliar genres of music on reading comprehension as well. Future studies could also evaluate characteristics like the typical volume or speed of songs within each specific genre, and how variations in these characteristics affect the relationship between reading comprehension performance and said genre of background music. Other factors to consider include evaluating both STM and WM's roles in the reading-music relationship using both digit span forward and digit span backward tests, or other memory tests. As most of the sample in both studies consisted of middle and high school students, familiarity with reading comprehension tasks in academic settings may also have affected reading task performance. The reading passages used were taken from free, publicly available SAT and ACT practice test materials, so familiarity with these materials or test formats may have influenced participant scores. Future studies on the reading-music relationship should consider generating new reading comprehension questions and passages for their tasks. Larger sample sizes, particularly for the neurodivergent sample in the study, would be a consideration for future validation of the results above.

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### Supplementary figures & tables are available at the following link:

https://docs.google.com/document/d/1gwZoBWazB1oJ7zJSx-ZlZub-vXsa1G_7/edit?usp=sharing&ouid=107789669893755153754&rtpof=true&sd=true