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A Study of the Effect of Phonological Loop Suppression on TMT-B Test Performance

Penelope Papagiannopoulou[1], Dimitrios Athanasopoulos[1], Polixeni Agapaki[1], Carolina Klonaridou[1], Georgios Vagiakis[1], Stavros Stergiatos[1], Panagiota Afendouli[2], Georgios Pilafas[3], Penelope Louka[4]

[1]Psychology Student, University of Derby (UK) at Mediterranean College Campus, Athens, Greece
[2]Accredited Lecturer in Psychology, University of Derby (UK) at Mediterranean College Campus, Athens, Greece
[3]Programme Leader 'BSc (Hons) Applied Psychology, University of Derby (UK) at Mediterranean College Campus, Athens, Greece
[4]Head of School of Psychology, Mediterranean College, Athens, Greece

Corresponding Author: Penelope Papagiannopoulou

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ABSTRACT

This study aimed to examine the impact of vocal music on cognitive performance using the Trail Making Test (TMT)-B. A sample of 90 participants was randomly assigned into two groups: one group listened to vocal music while completing the TMT-B, while the other group performed the task without any music. The TMT-B was specifically chosen as it incorporates the central executive, particularly the phonological loop, enabling more targeted findings. Our hypothesis posited that participants exposed to vocal music would exhibit lower performance on the TMT-B test due to the distraction caused and the suppression of the phonological loop. Statistical analysis was conducted using the Mann-Whitney U Test. Results revealed a significant difference in completion time between the two groups (with a large effect size d=0,95), with the group with vocal music taking longer to complete the test compared to the group without music. This suggests that vocal music interference has a negative impact on TMT-B performance.

Keywords: Working memory • Phonological loop Suppression • Processing speed • Cognition • Trail Making Test

INTRODUCTION

Information processing is one of the cognitive functions that, according to Ising, forms the basis of synthetic abilities, such as executive function, which requires attention to function.[1] An important part of cognitive psychology and neuroscience is the study of the phonological loop (PHL) because it plays a crucial role in perception, cognition, and action and influences the choices we make. [2]

In the last century, studies on cognitive processing have shown serious limitations in the ability to perform many tasks simultaneously.[3] A common way of measuring attentional information processing, and other cognitive skills, is thought to be the Trail Making Test (TMT test) which was introduced by Partington in 1949.[4] The reason why the TMT test is one of the most widely used tests worldwide is due to its ability to detect neuropsychological characteristics with high accuracy.[5,6] Several cognitive abilities are required such as visual search, perceptual speed, information processing speed, cognitive interference, cognitive shifting, and general intelligence. (7-10) The TMT test is divided into TMT-A and TMT-B. The TMT-A requires the participants to connect a series of circled numbers in numerical order, while in TMT-B, they connect a series of circled numbers and letters, alternating between ascending numerical and alphabetic order. (11-14)

The TMT-B test is a neuropsychological test that assesses various aspects of cognitive functioning, including visual attention, cognitive flexibility, mental processing speed, executive functioning, and the ability to alternate between two cognitive sets of stimuli. [15] It is one of the most widely used neuropsychological tests in clinical practice to evaluate cognitive deficits and detect impairments in individuals with various neurological conditions.[16,17] There has been past research on the TMT-B test regarding distraction as well as the good performance of the test in terms of working memory and has made it a very widely used test in the research community.[18] Working memory (WM) refers to the cognitive process that involves temporarily storing and manipulating information in the mind while engaged in a particular task.[19] In the context of TMT-B, WM would include the ability to remember and mentally manipulate the sequence of numbers and letters while associating them in the correct order.

The structure of WM is a subject of ongoing debate. All functions for everyday life go through WM. From reading a book to participating in a conversation, everything happens because of it. The basic model to describe WM was presented in 1974 by Baddeley & Hitch and is currently the most universally acknowledged theory of WM. [20,21] Before this model, Atkinson's & Shiffrin's Multi-Store Model (1968) incorporated the notion that cognitive tasks, such as acquiring knowledge and reasoning, require a mental workspace to grasp and orchestrate information.[22] The WM model involves five key components - the central executive, the visuospatial sketchpad, the phonological loop, secondary "slave systems," and the episodic buffer. [23,24] Whilst the visuospatial sketchpad's function is temporary visual storage, the PHL's function is the temporary storage for inner speech, essential for verbal comprehension and acoustic rehearsal.[25] The PHL consists of two modules, phonological storage which contains data for memory purposes, and subvocal rehearsal. Subvocal rehearsal is the component that provides information for phonological storage. Its function is likened to mental repetition, performed to decipher visual information into phonological code for short-term memory. This is the process that maintains new incoming information from decay.[26] Speaking – even if meaningless such as repeating a number, whilst reading text has shown inhibition of subvocal rehearsal. This inhibition does not allow for the storage or deciphering of new information and is termed articulatory suppression. When information is exhibited visually, as opposed to aurally, articulatory suppression appears to be enhanced.[27]

According to Baddeley, the functions of the PHL are believed to be supported by specific brain regions, such as the left posterior inferior frontal gyrus and the anterior supramarginal gyrus.[28] Recent behavioral findings suggest that both verbal and nonverbal auditory information may be processed within a general short-term storage center in the dorsal auditory stream region, rather than relying on specialized subsystems such as the PHL.[29] According to Baddeley's update of the WM model, [26] the PHL is involved, with anything verbal, even music with lyrics and environmental sounds.[30] However, Suarez L. et al. said that it remains uncertain whether the PHL plays a role in music processing as well. [31]

Researchers, however, argue that it is easy to handle two pieces of information simultaneously if they come from different loops.[19] However, in the case where there is a lot of information coming from one loop, the need for more processing time, and more effort to achieve any result becomes apparent. The information is all phonologically encoded and very difficult to retain. This is due to the phenomenon of phonological loop oversaturation (phonological loop suppression).[30]

Although, information in the phonological store lasts very little, approximately 2 seconds and for it not to be forgotten, it must be rehearsed with the articulatory control process. Auditory verbal data accesses directly the phonological store, while verbal information that is provided visually must first be converted into an auditory form by the articulatory control process. Twenty years after their initial proposal of their working memory model, Baddeley & Hitch suggested that articulatory suppression interacts with stimulus modality, as it prevents visual information from being translated into an auditory form.[32]

However, background music, which is acoustic and contains phonological information, can overload the PHL.[33] The presence of background music, as Cowan observed, reduces the accessibility of memory during the learning process. [34] This phenomenon prompts research on the interaction between background music and WM capacity. Furthermore, research examining the relationship between PHL, and music processing has yielded inconclusive results. Some researchers argue that Baddeley and Hitch's WM model of music needs an additional module to explain music processing, while others suggest that music is processed similarly to verbal sounds within the PHL.[19]

Music, particularly in relation to cognitive task performance, has been shown to have both positive and negative effects in different ways.[35] That is, directly and positively, through the “Mozart effect”, indirectly through the “arousal-mood hypothesis”,[36] whereby background music does not directly influence cognitive abilities but affects them by impacting on arousal and mood, and by inducing an additional burden on WM and therefore hindering cognitive performance.[37,38] Furthermore, they are mainly influenced by the rhythm of the song, whereas overstimulation can lead to fragmented emotions such as anxiety.[37] Additionally, they argued that the increased cognitive performance observed when people listen to background music is attributed to the experience of a pleasant stimulus. The rhythm and style of the music must be appropriate to evoke the intended stimulation and mood in the learner. [37]

However, Thompson & Yankeelov (2012) showed the possible need to revise the PHL model by incorporating a caching subset specifically dedicated to music processing. [39] The information stored in the PHL decays after about 2 seconds, at which point it must be projected using the modular control process to maintain its active state.[33] While the acoustic verbal material can be directly accessed in the phonological store, the visually presented verbal material must be converted to acoustic form through the process of modular control. Based on their analysis, Baddeley, and Hitch concluded that there is an interaction between articulatory suppression and stimulus form, preventing the conversion of visual stimuli into auditory representations.[33]

It is meant that, in the case of a visual stimulus, this is read by the phonological loop through the recoding of subvocal processes, while background music competes with sources of attention by the same field, the phonological loop. An argument in support of this is proposed by Salamé and Baddeley found that short-term memory performance (particularly verbal memory) was disrupted by background music, and the disruption was more pronounced for vocal music.[33] They suggested that this disruption may occur for other cognitive tasks of the phonological loop, such as reading, counting, calculating, and reasoning.

Research concerning music and the PHL remains inconclusive and there are suggestions that the working memory model requires another component (or additional subcomponents) for music processing, as Baddeley’s model does not fully account for different degrees of interference between language and music.[39] More specifically, Berz argued that working memory for music

could operate independently of verbal working memory.[40] Others have proposed similar WM mechanisms for different types of auditory information, including music.[41]
So far, different theoretical approaches have been employed to explain the effect of background music on various cognitive tasks, such as memory or learning with the definite mechanism still being unclear.[37,39]
Furthermore, an attempt was made to investigate the correlation between different loops such as phonological and time perception in an unpublished article from 1998,[18] as well as the use of the TMT-B test in older people to investigate the decline in cognitive abilities over time. The results of these studies showed that although the phonological loop has limited capacity, it can receive information from more than one source.[42] It was to be investigated whether the completion of the TMT-B test is affected by this process.
To our knowledge, there are no contemporary studies that use both the TMT-B test and phonological loop in combination effect. According to Hubbard, this was since research from 1960 to 2005 focused on visual imagery and spatial imagery.[43] However, according to the researcher, what is useful daily is imagery for auditory features and there are not enough studies on this. The novel of this study lies in the fact that it aims to investigate whether the processing time of phonetically encoded information is affected during PHL suppression, and the experimental hypothesis is that PHL suppression affects TMT-B performance.

METHODOLOGY

Design: This study used an independent measures design to examine the effect of music, as a suppression stimulus in the PHL, on the attention of performance time in conducting the Trail Making Test – B. The independent variable (IV) was the Phonological Loop Suppression (nominal variable), with two levels: with vocal music (group A) and without vocal music (group B). The dependent variable (DV) was the time taken to complete the TMT-B test (scale variable).
Participants: The study consisted of 90 participants (N = 90) fluent in the Greek Language and all of them had completed at least secondary education. The choice of the number of participants was based on previous research that had correlated music with cognitive abilities, and there the participants in the study were 40 participants in each group, therefore we placed 45 participants in each of the two groups.[44] They were all over the age of 18, with a range from 18 to 65 a mean age of 37.44 years, and a standard deviation of SD = 11.16486 years. Of the 90 participants, 43 were male and 47 were female. Sampling was convenient and there was a snowball effect as they suggested others to participate. Eligible participants were adults who declared themselves to be healthy and not suffering from an auditory condition, visual disturbances that would prevent them from completing the test, distraction, or some other medical problem that would make it difficult for them to perform the experiment. If someone had such problems, they would not be able to participate in the experiment. We also excluded people under the age of 18, and people in special vulnerable categories that would require us to obtain special approvals for participation.
Materials: For the vocal music condition (group A) the song used was the "Bar To Navagio" by Arletta – 1991, Lyrics: Arletta Music: Arletta Time: 3 minutes and 45 seconds. The song was chosen as a "favorite" by Greek people and of low tempo (tempo 112 Moderato Ushak scale) suitable according to Mollakazemi (2019) for cognitive science research.[45]
The materials used were the following: consent forms, participation forms, written instructions brief and debrief forms, all for the participants' consent and awareness. We provided the participants with printed versions of the adapted Trail Making Test – B, and translated the letters to Greek. A pencil, a timer, a score sheet, and a mobile phone with a song were also used for the

experiment. Finally, the Statistical Package for the Social Sciences Software (SPSS) was used for the screening of data and assessment.

PROCEDURE

The participants were informed about the experiment a few days in advance, the aims of the study, and the inclusion requirements of the experiment. The experiment was conducted in the laboratory facilities of the Mediterranean College in Athens to exclude external variables. On the day of the experiment, they were informed again in person about what the experiment was about and assured of their eligibility to participate. They were given the participant information form and the consent form where they were given a unique code. They then completed and signed the above forms where necessary. Participants were explained that they had the right to leave the experiment at any time they felt they wanted to. Participants were given the TMT-B test and one group completed it in silence while the other completed it to the sound of the chosen piece of music and completion times were recorded. The whole procedure took approximately 15 minutes for each participant. These completion times, together with the signed participation forms, were handed to the research team who thanked them for their participation in the experiment and gave them the information sheet with a reminder that they still had a few days to decide whether the data collected would be part of the research or if they want to withdraw it they can do so by contacting us at the details on the form with the code on the form.

Ethics: the whole survey was conducted in full alignment with the British Psychology Society's code of ethics. All necessary forms were given to the participants and unique codes to each of them to maintain their anonymity. Furthermore, all participants were informed of their right to discontinue at any time if they wished as well as to request within a reasonable time that their results be removed from the study. The supervisor professor was responsible for monitoring and ethical approval.

RESULTS

Firstly, a check of parametric conditions for normality was performed. The scores were converted to z scores to show if there were outliers (with a criterion of ±3 for samples N<100), so to be found and converted to mean values according to Field to be neutralized.[46] No outliers were found at all. Furthermore, by calculating the Skewness & Kurtosis measures for each IV level and with a criterion of ± 1.96 (N=90), it was found that for the IV condition (with music): *Z(skewness)=1.906 & Z(kurtosis)=0.14*. For the IV condition (without music): *Z(skewness)=3.92 >1.96 & Z(kurtosis)=2.85 >1.96*. So, a significant deviation was shown. Additionally, it appears from the histograms that there were positive skew and leptokurtic.

Then, Kolmogorov-Smirnov & Shapiro Wilk normality tests showed different p-values for each condition of IV. That is, the TMT-B completion time data appeared to deviate significantly from the normal distribution. Furthermore, testing the homogeneity of variance using Levene's test for Equality of Variances showed *f= 6.282 and Sig. = 0.014 < p = 0.05* (while the criterion of this test is p > 0.05) which is statistically significant and thus the parametric requirement for generalization does not apply.

Therefore, the parametric conditions were not met so a non-parametric test was done and hence Mann-Whitney U Test was used to analyze the data. The results are listed in Table 1 below and it can be seen that the 1st group, which was listening to music during the process of conducting the TMT-B test, took more time to implement the test with a higher mean than the group that did not listen to music and corresponding higher standard deviation, i.e. *Mean (with music) = 100.84 > Mean (without music)= 72.68 and St.Dev (with music) = 36.84 > St.Dev (without music)= 22.91*.

Table 1: ***Mean/Media & Std. Deviation/IQR for the two conditions of IV.***

	Mean / Median	Std. Deviation / IQR
With vocal music	100,84 / 96,00	36,84 / 42,00
Without vocal music	72,68 / 66,00	22,91 / 29,50

Since a non-parametric test was used, the Interquartile Range (IQR) results are shown respectively: *IQR (with music) =42.00, IQR (without music) =29.50* and we see that there are similar differences.

Moreover, from Mann-Whitney *(Mann-Whitney U (n_1 = 45; n_2 = 45) =505,00, z= -4,097, p <0,01, two-tailed)*, and there was a large effect size (Cohen's d= 0,95) which indicates that there was a statistically significant difference, and the Ho is rejected, so the TMT-B performance will be affected while listening to vocal music.

DISCUSSION

The rejection of the null hypothesis (H_0) was proposed based on the discovery of a small effect size (d = 0.181, p < 0.05), as indicated by Cohen.[47] This finding demonstrates that the effect observed falls below the predetermined alpha level, supporting the decision to reject the null hypothesis. Putting all these findings together, a sample of 332 participants would be suggested for the repetition of this study, for power = 0.8.

Results showed that there was a significant difference between the performance of TMT-B between those listening to vocal music, compared to those who did not listen to music at all. So, the PHL was suppressed, taking into consideration one of the outcomes of Baddeley's model (1986) that lyrics of the song, as auditive texts, might load the phonological loop, as referred to in Lehmann and Seufert.[37] However, it is worth mentioning that contrary to the assumptions of these researchers, in the current study the familiar song seemed to affect the performance of the TMT-B test negatively instead of leading to an easy and fast competence.

However, the TMT results have shown that individuals may have varying results without any distractions involved. Speed and fluid cognitive abilities have been noted to interfere with TMT performance results.[10] Other factors that must be considered are aging, such as people who are bilingual, dyslexic, or have ADHD, and even the relevance of the dominant side of their brain. The use of Functional Magnetic Resonance Imaging (fMRI) and Positron emission tomography (PET) techniques in studies have shown that a PHL takes place in specific parts of the brain. More specifically, studies have consistently found that subvocal rehearsal activity is found in the left inferior frontal area of the brain.[48] Other studies have found that the PHL implicates activity in the temporal lobe and left hemisphere of the frontal and parietal lobes.[25] However, these areas are also implicated in other parts of working memory, such as executive control. TMT-B has also shown implications for the frontal and parietal lobes that have however been attributed to the visuospatial sketchpad component.[49] It is still not concisely evident that all these factors indicate that the phonological loop component of Baddeley & Hitch's WM Model treats music as words.

Why do some participants take more time when listening to music with lyrics? Do they require more subvocal rehearsal because of music interference? It remains unclear which cognitive abilities are responsible for the TMT test. There is still ambiguity regarding whether the TMT test can restrict one cognitive function from another for measurement purposes.[9] Nevertheless, this study showed clear effects of vocal music on the completion time of the Trail Making Test – B, and more specifically, the time of participants who completed the test while listening to a well-known Greek song was larger than that in the control group, indicating an interference effect of vocal music to the cognitive task. According to the existing bibliography, it was assumed that listening to background music with lyrics while performing a cognitive task consumed cognitive capacity that would otherwise be invested in the task, as the capacity of working memory is limited. Working memory capacity is very important when performing a cognitive task because all information is processed within it.[37] Salamé and Baddeley (1989) claimed that it is impossible not to process auditory information, and precisely this information is always processed first.[33] Therefore, only if there are enough memory capacity resources can one invest in the task, after processing the auditive information. Additionally, lyrics would require additional processing.

By comparing with previous studies by Thompson & Yankeelov,[39] and Kattner & Meinhardt,[20] the findings support the view that music, particularly vocal music, can have detrimental effects on cognitive performance. While Thompson and Yankeelov highlighted the different effects of irrelevant speech and music on tonal and phonological recall tests, our study focused on the TMT-B test. In addition, Kattner & Meinhardt investigated the effect of different types of auditory distractions on memory processes. Our study extends these findings by specifically investigating the interference of vocal music on WM and task-switching abilities. The significant difference in TMT-B completion time between participants who listened to vocal music and those who did not align with the negative effect of music interference was found in previous research. The findings of this study enhance our understanding of the impact of musical interference on cognitive performance and support the need for further investigation of the mechanisms underlying these effects.

In the field of cognitive neuropsychology of phonological short-term memory (pSTM), the results seem to confirm general research on the PHL, such as Schendel's where suppression of loops seems to lower efficiency.[50]

The results are consistent with the study of cognitive properties as well as the function of short-term memory as described by the theoretical models of Baddeley and Hitch, consistent with expected behaviour and with functional models.[51]

Since suppression was achieved, therefore there is WM different from long-term memory and so it seems that the model put together by J. Nairne who believes that there is no WM but only long-term memory, but which is of infinite capacity and therefore could not undergo suppression, is not valid.[52]

The results are further consistent with Craik's research on WM and the PHL where he showed reduced abilities and longer processing times when more than one piece of information of the same type is requested to be processed.[53] An inherent limitation of this study was the use of a convenience sample. and the focus on a specific age range and language group (native Greek speakers), which may limit the generalizability of the findings. Moreover, there are currently no studies directly linking TMT tests to phonological loop suppression and music interference. What is more, the experimental condition included only one song and we didn’t examine the differences that would occur if diverse musical samples were used, with different music characteristics, as well as other meaningful sounds. The obtained result would also need to be validated by measuring the cognitive load after the test with and without background music.

After conducting this experiment, it was undeniably confirmed, similarly to Foos and Goolkasian’s findings that the allocation of attention determines the highest results of the task, as suggested.[54] What is worth mentioning, is that when the subjects were given the test to complete, they did their best to satisfy the requirements of the Hawthorne effect.

As far as the present study is concerned, two previously learned processes are being recalled during the completion of the Trail Making Test (TMT). These processes involve sequential information already known to the brain, specifically the alphabet and the ascending order of natural numbers. The condition is that one is interposed within the other, alternating between letters and numbers, while simultaneously locating the next element. The time pressure to complete the task, the expectation to satisfy the researcher (demand characteristics), as well as the Hawthorne effect, are all considered. In future studies, it would be beneficial to consider including a more diverse sample and explore possible cultural and linguistic factors associated with vocal music and cognitive performance.

Tables

Figure 1: Male & Female participants

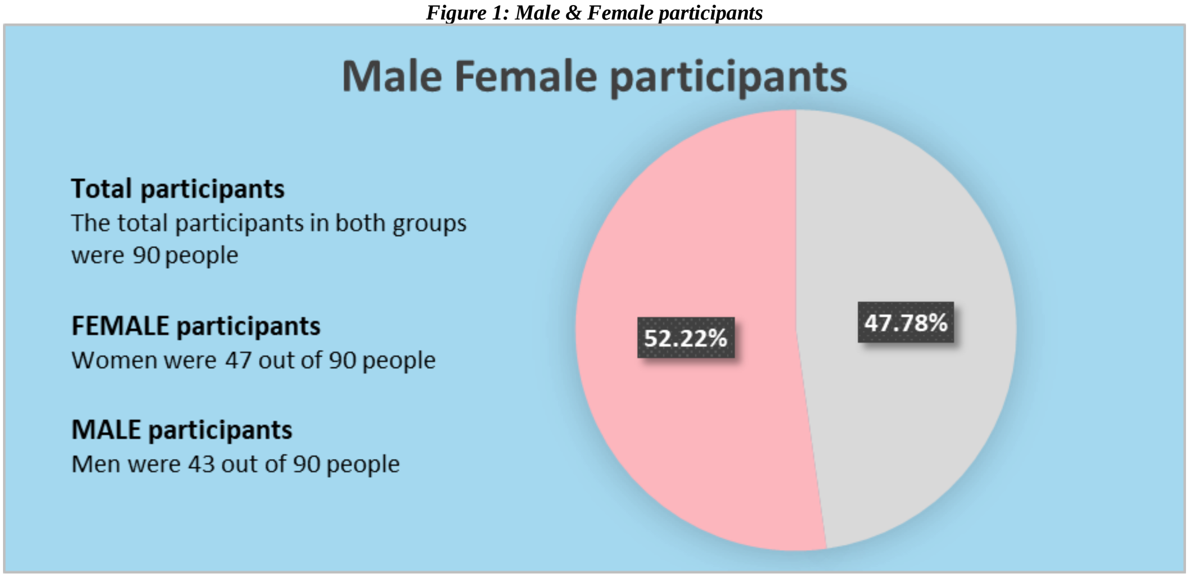
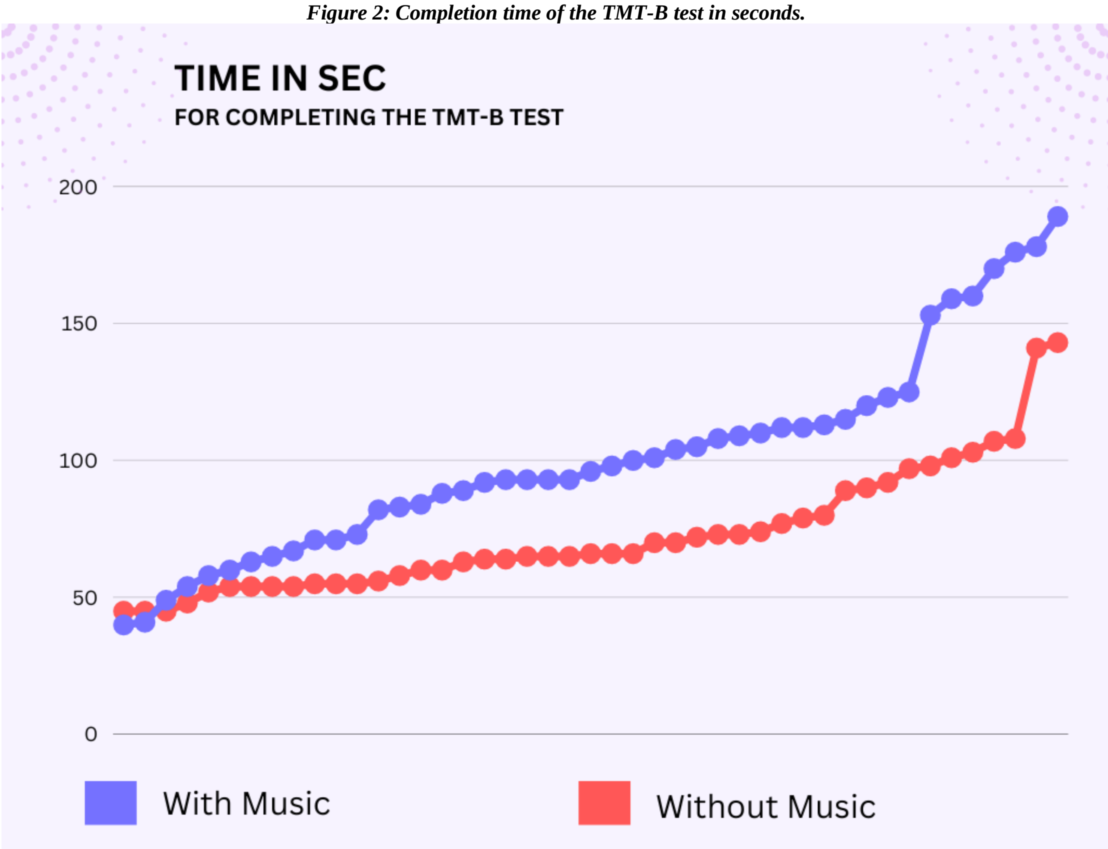


Figure 2: Completion time of the TMT-B test in seconds.



Declaration by Authors

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