The Effects of Self-Selected Background Music and Task Difficulty on Task Engagement and Performance in a Visual Vigilance Task

Lauren A. Homann, Allison C. Drody, and Daniel Smilek

Department of Psychology, University of Waterloo, Waterloo, Ontario, Canada

Author Note

Correspondence concerning this article should be addressed to Lauren A. Homann, Department of Psychology, University of Toronto, 100 St. George St., Toronto, ON, Canada, M5S 3G3, Email: lauren.homann@mail.utoronto.ca

Orchid IDs: Lauren A. Homann [0000-0002-4019-7376], Allison C. Drody [0000-0001-8366-7035].

Acknowledgements

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) through an NSERC Discovery Grant (RGPIN-2019-04071) awarded to author Daniel Smilek. We thank Sukhman Dhanona, Stuart Morden, and Brian Kim for their assistance in data collection.

Abstract

Listening to self-selected background music has been shown to be associated with increased task focus and decreased mind wandering during a sustained attention task (Kiss & Linnell, 2021, *Psychological Research*). It is unclear, however, how this relation may depend on the potentially critical factor of task difficulty. To address this knowledge gap, we explored how listening to self-selected music, compared to silence, affects subjectively experienced task engagement (i.e., task focus, mind wandering, and external distraction/bodily sensation states) and task performance during either an easy or a hard vigilance task. We also examined how these effects vary with time-on-task. Our results replicated prior work demonstrating that background music enhanced task focus and decreased mind wandering, compared to silence. There was also lower reaction time variability in the background music condition relative to the silence condition. Notably, these findings held regardless of task difficulty. Interestingly, when examined over time-on-task, the presence of music led to smaller task focus declines and mind wandering increases, compared to silence. Thus, listening to self-selected music appears to confer a protective effect on task engagement, especially over time-on-task.

Keywords: background music, mind wandering, task engagement, sustained attention, task difficulty

The Effects of Self-Selected Background Music and Task Difficulty on Task Engagement and Performance in a Visual Vigilance Task

With recent technological advances, music is increasingly accessible in daily life. As a result, individuals now have greater autonomy to choose how and when they engage with music, giving rise to complex listening patterns dependent on the time of day, mood, and activity (Krause et al., 2015). These music listening routines are also trending, perhaps concerningly, towards being concurrent with attention-demanding tasks while working or studying (North et al., 2004). Given the commonality of this behaviour, it is important to explore how background music affects both attentional processes and primary task performance. Therefore, we examined how listening to self-selected background music influences both vigilance task performance, as well as subjectively experienced task engagement. To determine whether these relations differ depending on task demands, we investigated how background music influences performance and engagement on both an easy and hard vigilance task. With the goal of ascertaining a more comprehensive picture of how background music influences sustained attention and performance, we also considered the variable of time-on-task.

Music, Task Performance, and Task Engagement

Overall, the extant literature is mixed with regard to how background music affects task performance, with studies demonstrating faciliatory (e.g., Crust et al., 2004; Davies et al., 1973; Fontaine & Schwalm, 1979; Ünal et al., 2013), detrimental (e.g., Cassidy & Macdonald, 2007; Cloutier et al., 2020; Deng & Wu, 2020; Millet et al., 2019; North & Hargreaves, 1999), and null (e.g., Cloutier et al., 2020; Deng & Wu, 2020; Nadon et al., 2021; Ünal et al., 2013) effects. In an effort to reconcile this diverse body of work, one meta-analysis found a global null effect of background music on task performance (Kämpfe et al., 2011). This null effect, however, is likely the result of opposing effects averaging out (Kämpfe et al., 2011). That is, background music can be either beneficial or detrimental to the task at hand, depending on the situation.

One factor that seems to influence the relation between background music and task performance is the cognitive requirements of the task: while music has been shown to have unfavourable effects on reading and memory processes, it positively influences emotional reactions and sports performance (Kämpfe et al., 2011). A second factor that may determine how background music affects performance might be the audio features of the background music. For instance, faster tempos regularly covary with faster motor behaviour (Kämpfe et al., 2011). Unfortunately, studies often differ in the type of music played to participants (e.g., lyrical vs. instrumental, high arousal potential vs. low arousal potential, participant vs. experimenter selected), rendering the task of interpreting the literature challenging. The inconsistent effects of background music on performance may also stem from issues related to study design. For example, some studies employ small sample sizes (e.g., Amezuca et al., 2005; Nethery, 2002) or lack a silence or noise control condition (e.g., North & Hargreaves, 1999).

When considering the effects of background music on task performance more generally, a useful concept that can help explain the discordance in the literature is arousal. It has been well-documented that different types of music can have different impacts on people's arousal (e.g., Bartlett, 1996; Burkhard et al., 2018; Pelletier, 2004). Indeed, music's ability to regulate internal states is a core reason why individuals choose to listen to music (Lamont et al., 2016), and this property of music can be leveraged to manipulate arousal in experimental paradigms (Chen et al., 2013; Fontaine & Schwalm, 1979; Ünal et al., 2013). Given these considerations, it seems likely that the multifarious effects of background music on task performance may reflect the complex relation between arousal and task performance.

The relation between arousal and performance is believed to follow the Yerkes-Dodson Law (Diamond et al., 2007; Yerkes & Dodson, 1908), whereby performance suffers when arousal is either too high or too low and performance peaks at an intermediate level of arousal. Changes in arousal have been shown to be associated with alterations in the rate of behaviourally-indexed attention lapses

(Hobbiss et al., 2019; Unsworth et al., 2018; Unsworth & Robison, 2016), as well as with shifts in subjective attentional states (Hobbiss et al., 2019; Unsworth & Robison, 2016). Specifically, when arousal is either too low or too high, individuals are typically inattentive or distractable, and lapses in attention occur (Hobbiss et al., 2019; Unsworth et al., 2018; Unsworth & Robison, 2016). At these points, if attention is directed internally, mind wandering may occur, and if attention is directed externally, individuals may become distracted by exogenous or endogenous stimuli that are unrelated to the current task (e.g., sounds or bodily sensations; Hobbiss et al., 2019; Unsworth & Robison, 2016). When arousal approaches an intermediate level, however, the individual is focused, attention lapses are minimized, and the individual reports being on task (Hobbiss et al., 2019; Unsworth & Robison, 2016). Critically, it is important to note that the effect of arousal on performance may depend on task difficulty: increased arousal can facilitate performance on easy tasks but hinder performance on more difficult tasks (Anderson, 1994; Diamond et al., 2007).

Available evidence points to arousal as a mediator of the relation between background music and performance on tasks requiring sustained attention (Fontaine & Schwalm, 1979; Kiss & Linnell, 2021; North & Hargreaves, 1999; Turner et al., 1996; Ünal et al., 2013; Wang et al., 2015). When tasks are simple, music may increase arousal towards an optimal level (the middle portion of the arousal-performance curve), improving performance. In contrast, when tasks are more complex, music may increase arousal beyond an optimal level (i.e., the right-hand side of the arousal-performance curve), thus interfering with performance. Several studies support this view (Fontaine & Schwalm, 1979; North & Hargreaves, 1999; Turner et al., 1996; Wang et al., 2015). For instance, when the mental workload of a driving simulator task was low, background music improved performance relative to silence; on the other hand, when mental workload was increased by manipulating the complexity of the driving environment (e.g., by increasing the number of unexpected peripheral obstacles), driving task performance was substantially worse in the music condition (Wang et al., 2015). As another example, when music was played at a comfortable level, reaction time on a psychomotor vigilance task was significantly faster compared to when music was presented at volumes that were lower or higher, as well as in a condition without music (Turner et al., 1996). Essentially, performance suffered when music volume was manipulated such that it was either too arousing or not arousing enough, mirroring the inverted-U-shaped curve of arousal and task performance.

When exploring the influence of background music on task performance, it is crucial to consider the consequences of music preference. The reason for this is that in their daily lives, individuals may select songs with the intentional or unintentional goal of titrating their arousal to optimal levels for performing the task at hand. Substantiating this claim, individuals in a recent survey reported listening to less arousing music when completing complex tasks such as reading or studying and listening to more energizing music when completing more monotonous tasks (Kiss & Linnell, 2022). Experimental results also corroborate these findings: when participants completed a driving task that included car sounds, they were most efficient when listening to self-selected music compared to experimenter selected music that was either high or low in terms of arousal potential (Cassidy & MacDonald, 2009). Additionally, when individuals performed a simple car-following task in a driving simulator in the presence of self-selected music or silence, preferred music increased arousal as indexed by heart rate and was associated with faster reaction times to actions of the car in front of them, as well as improved lateral control of the vehicle (Ünal et al., 2013).

To our knowledge, only a couple of studies have assessed the influence of background music on subjective attentional states, such as mind wandering, while individuals complete a concurrent task (Feng & Bidelman, 2015; Kiss & Linnell, 2021). The most relevant study to this paper examined how self-selected background music versus silence affects subjectively experienced task engagement during a psychomotor vigilance task (Kiss & Linnell, 2021). This research revealed that, compared to silence, listening to background music was associated with an increase in the proportion of task focus states (i.e., "I am focused on the task or how I am doing it") and a commensurate decrease in the proportion of mind wandering states experienced by participants. Moreover, task focus states correlated with better performance, as indicated by shorter reaction times. These findings can be accounted for by the hypothesis that arousal mediates the relation between background music and task performance. In accordance with this hypothesis, the self-selected background music in this study likely increased arousal to an optimal level for the vigilance task, which was relatively easy to complete, thereby enhancing task focus states and facilitating performance.

However, there are several questions that remain unanswered regarding these findings. First of all, the mind wandering probe combined mind wandering with tiredness and mind blanking (i.e., "I am tired, my mind is blank, or my thoughts are elsewhere") and so it is difficult to know which of these experiences specifically was influenced by the presence of music. Second, it remains unclear how the addition of background music would impact subjective states of engagement (e.g., mind wandering) if participants are given a much harder primary task. Assessing the influence of background music when individuals perform tasks under varying levels of difficulty would further probe the arousal curve and offer a more complete view of how background music affects task performance and engagement. When one completes a difficult task (as opposed to an easier task, as in Kiss & Linnell, 2021) while listening to self-selected music, it is possible that arousal would surpass an optimal level, and task engagement, along with performance, would suffer as a result; it is also uncertain whether such disengagement would be characterized by states of mind wandering or attention to external distractions/bodily sensations.

The Present Study

In two samples, we extended prior work (primarily Kiss & Linnell, 2021) in three main ways. First, we investigated how the effects of listening to self-selected background music on subjectively experienced task engagement and task performance may be influenced by variations in primary task difficulty (which is assumed to influence overall arousal). To do this, we had participants complete either an easy or hard vigilance task requiring a perceptual discrimination decision while listening to self-selected background music and in silence. Task difficulty (easy or hard) was manipulated between-participants by varying the discriminability of the stimuli in the vigilance task. Second, we examined how this potential interaction between listening condition and task difficulty may vary with time-on-task. Third, we assessed probe-caught subjective attentional engagement in a more precise and comprehensive way. Specifically, we assessed the degree of task focus, mind wandering (which was evaluated as a unique construct from fatigue and mind blanking), and external distraction/bodily sensation states, each indexed by separate continuous rating scales. These probes allowed us to observe more subtle differences in subjective reports of engagement than has been done in prior work on music and attention (Kiss & Linnell, 2021). Moreover, this measure allowed us to capture a more complete picture of participants' engagement, as they could report varying degrees of different attentional states simultaneously (e.g., partially mind wandering, partially on task).

We hypothesized that there would be a listening condition by task difficulty interaction on both task performance and the degree of task focus states. We predict this based on findings that have demonstrated that preferred (Cassidy & MacDonald, 2009) and familiar (Fontaine & Schwalm, 1979) background music increases arousal. When this research is taken into the context of the hypothesis that arousal mediates the relation between background music and performance, arousal should be more likely to increase to an optimal level in the music condition, but only when task demands are lower (the easy task). This optimal increase in arousal should be associated with a higher degree of task focus states and higher performance in the music condition relative to the silence condition. Improved performance should present in any one or more of the following ways: an increase in hit rate, a decrease in false alarm and omission rates, as well as a decrease in mean reaction time and reaction time variability. However, when task demands are high (the hard task), arousal will presumably increase beyond a level that is beneficial to the task at hand. In this scenario, the degree of task focus states and task performance should decrease under the music condition relative to silence.

Second, we hypothesized that there would be no listening condition by time-on-task interaction for either task focus states or task performance. The literature related to this prediction presents mixed results, leaving room for further investigation. While some research reports no time-on-task by listening condition interaction on task performance, suggesting that performance declines at similar rates regardless of the presence of music (Burkhard et al., 2018; Kiss & Linnell, 2021), other studies suggest that music may mitigate the traditional decrement in vigilance task performance over time (Davies et al., 1973; Fontaine & Schwalm, 1979). In contrast, there is some evidence to suggest that the vigilance decrement might actually be larger under background music. This interaction, however, may only materialize with longer vigils. Supporting this idea, in one study, arousal (as indexed by heart rate) remained significantly higher in a music condition compared to a silence condition for the first 20 minutes of a 30 minute task, after which the difference between groups became smaller as individuals began to habituate to music (Ünal et al., 2013). Considering this work in the context of the present study, we can surmise that arousal should remain significantly higher in our self-selected music condition compared to our silence condition for the entirety of our 20-minute vigilance task. Thus, in light of the relationship between arousal and performance (Diamond et al., 2007), we opted to predict that performance on our vigilance task should worsen over time (i.e., the vigilance decrement; Parasuraman & Mouloua, 1987) to a similar extent regardless of the presence of background music. Likewise, we expected the degree of self-reported task focus states to decrease over time (Thomson et al., 2015) to a similar extent across listening conditions.

Method

Participants

This study was approved by the Office of Research Ethics at the University of Waterloo, and all participants gave informed consent before participating in the study. All participants were undergraduate students recruited from an online participant pool at the University of Waterloo who self-selected to participate in exchange for course credit. Eligible participants reported having normal or corrected-to-normal vision and hearing in a pre-screen questionnaire to ensure they could properly hear the music and complete the visual vigilance task. We did not restrict our sample to consist only of individuals who normally listen to music while performing attention-demanding tasks, unlike prior work (Kiss & Linnell, 2021). Importantly, this decision to recruit a broader sample allowed us to investigate the generalizability of past findings. Since our samples were otherwise collected at random, any matching on participant characteristics such as age or sex was due to chance. We collected data from a small pilot sample followed by two full samples. Sample one was collected first. Then, to confirm our findings, we collected a second sample. Sample two was a direct replication of sample one. We then examined if the findings were consistent across samples.

Pilot Study

Twelve individuals (ten female, two male), ranging in age from 18 to 34 (M = 21.83, SD = 4.49), participated in the pilot study. The pilot study was run to ensure that difficulty was sufficiently manipulated for the vigilance paradigm and that technical issues would be minimized.

Sample One

We used a heuristic-like approach in selecting our sample size (Lakens, 2022). As the current study has a similar design to Kiss and Linnell (2021) with one additional between-participants variable, we multiplied their sample size (N = 40) by three to get a final sample size of 120 participants with 60 in each task difficulty group (easy or hard). Sample one therefore consisted of 120 participants, with data collected between September and December of 2021. Participants were excluded from analyses if they were unresponsive to 15% or more trials in either the music or silence condition, indicating noncompliance. This led to the exclusion of five participants in the easy group and three participants in the hard group. Also, seven participants were excluded from formal analyses due to technical issues with music streaming (*n* = 4), getting interrupted by individuals in their testing environment (*n* = 1), or not complying with instructions (*n* = 2). The final sample used in formal statistical analyses therefore consisted of 105 participants, with 53 participants in the easy group (38 female, 15 male), ranging in ages from 17 to 49 (*M* = 21.19, *SD* = 4.84), and 52 participants in the hard group (42 female, 10 male), ranging in ages from 17 to 42 (*M* = 21.42, *SD* = 5.26).

Sample Two

Sample two also consisted of 120 participants, with 60 participants in each task difficulty group. Sample two was collected between February and May of 2022. The exclusion criteria were identical to that of sample one. Two participants in the easy group and six participants in the hard group were excluded for having omission rates greater than 15% in either the music or silence condition. As well, eight participants were excluded from formal analyses due to technical issues with music streaming (*n* = 1), getting interrupted by individuals in their testing environment (*n* = 3), or not complying with instructions (*n* = 4). The final sample used in formal statistical analyses therefore consisted of 104 participants, with 53 participants in the easy group (35 female, 18 male), ranging in ages from 18 to 34 (*M* = 19.68, *SD* = 2.86), and 51 participants in the hard group (35 female, 16 male), ranging in ages from 17 to 42 (*M* = 19.76, *SD* = 3.74).

Sensitivity Analysis

A *post-hoc* sensitivity analysis was conducted using G*Power (Faul et al., 2009) to determine the minimum detectable effect size of the two-way task difficulty by listening condition interaction. We chose this interaction as the target of the sensitivity analysis because our critical hypothesis was that the influence of listening condition on task performance and task focus states would depend on task difficulty. The sensitivity analysis revealed that with a sample size of 104 (the smaller of our two samples), 80% power, and an alpha of .05, we were sufficiently powered to detect a small to medium effect size (*f* = 0.14).

Materials and Procedure

The materials and procedure were identical for both sample one and sample two. All materials, experiment files, data, and statistical code can be found on the Open Science Framework (https://osf.io/n9w5m/).

Listening Habits

Participants were asked: "In general, how often do you listen to music while performing attention-demanding tasks (i.e., studying, working)?". Response options ranged from 1 (*never*) through 5 (*always*).

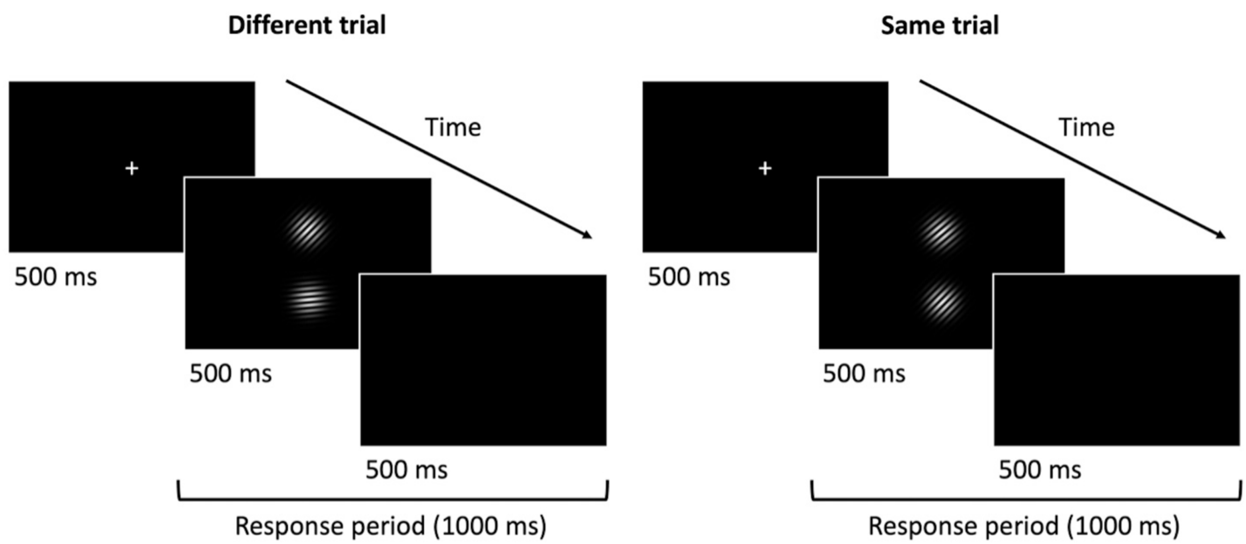
Vigilance Task

The primary task was a perceptual decision task in which participants determined whether two Gabor patches (circular patterns with alternating grey and black bars), presented in black and white on a black background, were both oriented in the same direction. We opted to avoid using linguistic stimuli, as music—especially with lyrics—may disrupt performance on sustained attention tasks relying on subvocal rehearsal (e.g., *SART, n*-back) due to irrelevant sound effects on short-term memory (e.g., Salamé & Baddeley, 1989).

At the beginning of each trial of the vigilance task (see Figure 1 for the trial sequence), participants saw a black screen with a white fixation cross for 500 ms. Next, participants saw two Gabor patches, both presented in the middle of the screen, one above the other. Each Gabor patch was 250 by 250 pixels and had a frequency of 0.05 cycles per pixel. The centers of both Gabor patches were 250 pixels apart. Gabor patches of the same orientation ("same" trials; both at 45°) or differing orientations ("different trials"; only one at 45°) were presented on each trial. Participants then had 1000 ms—beginning from the moment the Gabor patches were presented and ending as soon as the next fixation cross appeared—to indicate whether the two Gabor patches were oriented in the same direction. The Gabor patches stayed on the screen for 500 ms of the 1000 ms response period and were replaced with a black screen for the remaining 500 ms. Participants indicated their response by pressing the 'z' or 'm' key of the keyboard with their left or right hand respectively, with the response rule counterbalanced between-participants. There were three blocks consisting of 210 trials each, with same trials appearing at a proportion of .10 (21 trials/block), in line with other similar vigilance paradigms (Parasuraman et al., 1989). Stimulus presentation and response recording were controlled by OpenSesame Experiment Builder (Mathôt et al., 2012). OpenSesame experiment files are available on the Open Science Framework (https://osf.io/n9w5m/).

Figure 1

Vigilance Task Trial Sequence



Thought Probes

Task engagement was measured using a probe-caught sampling method intended to measure participants' degree of task focus, mind wandering, and external distraction/bodily sensation states. All probes were presented in white text on a black background. The task focus probe, adapted from Franklin and colleagues (2011), asked participants: "In the moment prior to the probe, to what extent were you focused on the task?". The mind wandering and external distraction/bodily sensation probes were adapted from Unsworth and Robison (2016). The mind wandering probe asked participants: "In the moment prior to the probe, to what extent were you daydreaming/mind wandering about things unrelated to the task?". The external distraction/bodily sensation probe asked participants: "In the moment prior to the probe, to what extent were you focused on sights/sounds/temperature or physical sensations like hunger/thirst?". For all probes, response options ranged from 1 (*not at all*) through 5 (*completely*), and participants selected one of the response options by pressing the corresponding number key on their keyboard. Higher scores on probes indicated a higher degree of task focus, mind wandering, or external distraction/bodily sensation, respectively. Each time task engagement was measured, participants first responded to the task focus probe, followed by the mind wandering and external distraction/bodily sensation probes in that order. Probes were presented until the participants responded, with a black screen presented for 500 ms between each response and the following probe.

Background Music

Self-selected background music was chosen to remain consistent with the methods used by Kiss and Linnell (2021) and maintain the ecological validity of the paradigm. Participants chose approximately 20 minutes' worth of music that they wished to listen to during the music portion of the study. As long as songs were available on Apple Music (for sample one) or Spotify (for sample two), there were no restrictions on music selection, and participants could choose to repeat songs (although none did). Participants typed out each song they wanted to listen to in the Zoom chat or verbally told the researcher which songs they wanted to listen to. The researcher then created a playlist of their self-selected songs on a private Apple Music (for sample one) or Spotify account (for sample two) to ensure ads would not play.

Some work suggests that the ways in which background music influences task performance may depend on musical properties such as tempo (Kämpfe et al., 2011), arousal potential (North &

Hargreaves, 1999), valence (Fernandez et al., 2020), or the presence of lyrics (Shih et al., 2012). While exploring whether different types of music produce similar effects on task performance and engagement was not the focus of the present work, for the sake of completion, we examined whether any differences in music tempo, energy (a proxy for arousal potential), valence, or the presence of lyrics existed across sample and difficulty groups. There were no significant differences in any of these musical properties between groups (see the Online Resource).

General Procedure

Participants completed the study remotely (using their personal computer) and individually while concurrently videoconferencing with the researcher using Zoom. The experiment took approximately one hour to complete. Participants were asked to use headphones for the duration of the study (although twelve participants did not have access to working headphones) and to leave their video camera on to encourage compliance (although nine participants either did not have access to a video camera or chose not to use one). After providing informed consent and self-reporting their age, sex, and listening habits via Qualtrics (https://www.qualtrics.com), participants created their music playlist with the researcher.

Participants completed the vigilance task in their web browser, as the task was hosted on a local university server using JATOS experiment manager (Lange et al., 2015). To access this vigilance task, participants followed a link sent to them by the researcher. Since the researcher was present over Zoom, they were available to help if any technical issues arose. Participants then completed 10 practice trials of an easy or hard version of the vigilance task. The version they completed matched the task difficulty condition to which they were assigned. The practice trials were always completed in silence. In the practice session, participants received feedback after each response, informing them whether their response was “correct” or “incorrect.” Participants also saw and responded to all three thought probes once in the session, presented at a random time point, to imitate what they were going to see in the experimental phase. The practice trials were not analyzed.

Next, participants began the experimental session. Participants were randomly assigned to complete either an easy or hard version of the vigilance task in two conditions: once with music present (20 minutes), and once in silence (20 minutes). The order of the listening conditions was counterbalanced between-participants. During the music condition, the researcher streamed music from their computer using the Zoom audio-sharing feature with high-fidelity sound. Task engagement was measured three times per time-on-task block, approximately once every 70 trials, for a total of nine times per listening condition. Probes did not appear in the first 10 trials of each 70-trial segment to ensure that a minimum of 10 trials would elapse between each time task engagement was measured. Probes were presented in a random position for the remaining 60 trials. After all three probes were presented and responded to, participants saw a screen asking them to press the space bar to continue the vigilance task. Between listening conditions, participants took a five-minute break intended to prevent carryover effects of music. During the break, participants played an online PacMan game (https://pacman.live) with the sound muted to mitigate fatigue and maintain engagement. After completing both sessions of the vigilance task, participants were debriefed and thanked for their participation.

Results

All statistical analyses were conducted using R with the tidyverse (Wickham et al., 2019), emmeans (Lenth et al., 2023), rstatix (Kassambara, 2023) and afex (Singmann et al., 2023) packages. We conducted a series of mixed 2 (listening condition: music or silence; within-participants) X 2 (task difficulty: easy or hard; between-participants) X 3 (time-on-task: 3 blocks; within-participants) X 2 (sample: sample one or sample two; between-participants) ANOVAs for each of the task performance and task engagement measures as dependent variables (see Table 1 for descriptive statistics). When

Mauchly's Test indicated that sphericity was violated, the Greenhouse-Geisser correction for degrees of freedom was applied where warranted. Levene's test was used to assess the homogeneity of variance assumption, and any violations are noted in their relevant sections. We proceed with reporting the results of the mixed 4-way ANOVAs in cases where there were minor violations of assumptions, as our ANOVAs should be relatively robust to these violations since our sample sizes are approximately equal and our group sizes are large. As we were not primarily interested in how the order of listening conditions influences our results, ANOVAs including the between-participants factor of order (music first or silence first) are available on the Open Science Framework (https://osf.io/n9w5m/).

Table 1

Means and Standard Deviations of Task Performance and Engagement Measures

Variable	Sample one						Sample two					
	Easy group (*n* = 53)			Hard group (*n* = 52)			Easy group (*n* = 53)			Hard group (*n* = 51)		
	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Hit rate												
Music	0.62	0.63	0.58	0.72	0.71	0.70	0.60	0.58	0.55	0.64	0.64	0.64
	(0.21)	(0.19)	(0.24)	(0.22)	(0.24)	(0.23)	(0.23)	(0.22)	(0.24)	(0.26)	(0.27)	(0.29)
Silence	0.63	0.57	0.55	0.71	0.71	0.70	0.61	0.58	0.56	0.66	0.67	0.59
	(0.22)	(0.24)	(0.22)	(0.21)	(0.21)	(0.20)	(0.22)	(0.21)	(0.21)	(0.26)	(0.25)	(0.28)
False alarm rate												
Music	0.04	0.03	0.02	0.20	0.18	0.20	0.06	0.05	0.05	0.22	0.21	0.22
	(0.10)	(0.08)	(0.06)	(0.16)	(0.14)	(0.14)	(0.13)	(0.12)	(0.14)	(0.17)	(0.18)	(0.18)
Silence	0.04	0.03	0.03	0.20	0.19	0.19	0.05	0.04	0.03	0.23	0.23	0.21
	(0.13)	(0.11)	(0.13)	(0.17)	(0.16)	(0.13)	(0.11)	(0.08)	(0.09)	(0.20)	(0.21)	(0.19)
Omission rate												
Music	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00
	(0.01)	(0.02)	(0.04)	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)
Silence	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.04)	(0.00)	(0.01)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)
RT – same (ms) [a]												
Music	547.35	559.43	564.95	551.15	551.44	551.48	535.72	544.37	545.63	522.80	519.96	515.36
	(55.84)	(66.75)	(67.16)	(79.94)	(77.85)	(73.91)	(79.76)	(66.23)	(83.20)	(88.64)	(91.05)	(69.39)
Silence	559.69	554.60	554.25	550.47	562.88	566.52	542.25	536.32	538.85	512.02	525.59	511.36
	(87.01)	(78.48)	(88.25)	(81.23)	(86.94)	(88.76)	(102.84)	(75.82)	(83.69)	(109.18)	(112.57)	(117.82)
RT – different (ms)												
Music	463.96	462.92	454.61	532.92	521.62	517.78	456.13	441.72	441.47	494.65	489.05	477.75
	(69.16)	(75.12)	(76.97)	(86.16)	(73.37)	(76.09)	(93.93)	(77.70)	(92.04)	(101.75)	(100.39)	(97.90)
Silence	462.99	449.78	438.65	526.56	517.96	522.35	465.73	444.14	434.43	489.80	491.27	471.50
	(87.26)	(87.10)	(83.43)	(86.60)	(83.64)	(88.91)	(103.14)	(83.77)	(77.77)	(123.82)	(122.44)	(118.82)
RTCV – same (ms) [b]												
Music	0.14	0.13	0.13	0.15	0.15	0.17	0.17	0.14	0.18	0.18	0.17	0.18
	(0.07)	(0.05)	(0.07)	(0.06)	(0.05)	(0.12)	(0.09)	(0.08)	(0.17)	(0.10)	(0.08)	(0.10)
Silence	0.15	0.14	0.15	0.17	0.15	0.17	0.17	0.17	0.18	0.20	0.19	0.22
	(0.05)	(0.06)	(0.09)	(0.07)	(0.07)	(0.12)	(0.16)	(0.16)	(0.15)	(0.13)	(0.13)	(0.16)

Variable	Sample one						Sample two					
	Easy group (*n* = 53)			Hard group (*n* = 52)			Easy group (*n* = 53)			Hard group (*n* = 51)		
	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
RTCV – different (ms)												
Music	0.21 (0.05)	0.21 (0.07)	0.22 (0.08)	0.21 (0.05)	0.21 (0.05)	0.21 (0.06)	0.25 (0.11)	0.25 (0.12)	0.24 (0.12)	0.23 (0.08)	0.22 (0.07)	0.22 (0.08)
Silence	0.23 (0.08)	0.23 (0.10)	0.23 (0.10)	0.21 (0.06)	0.21 (0.07)	0.21 (0.07)	0.24 (0.12)	0.26 (0.19)	0.25 (0.13)	0.25 (0.14)	0.25 (0.19)	0.25 (0.16)
Task focus												
Music	3.88 (0.78)	3.83 (0.90)	3.59 (0.95)	3.96 (0.83)	3.76 (0.86)	3.67 (0.78)	3.96 (0.73)	3.75 (0.89)	3.60 (1.05)	3.96 (0.74)	3.66 (0.91)	3.41 (1.07)
Silence	4.02 (0.78)	3.53 (1.03)	3.35 (1.06)	4.08 (0.70)	3.67 (0.87)	3.36 (0.98)	3.99 (0.92)	3.75 (1.01)	3.43 (1.15)	3.76 (1.00)	3.47 (0.97)	3.14 (1.10)
Mind wandering												
Music	2.06 (0.84)	2.18 (0.85)	2.39 (1.02)	2.06 (0.81)	2.34 (0.99)	2.34 (0.97)	2.07 (0.79)	2.20 (0.89)	2.25 (0.89)	2.18 (0.88)	2.51 (1.08)	2.73 (1.17)
Silence	2.21 (0.84)	2.55 (1.04)	2.67 (1.05)	2.09 (0.67)	2.53 (0.95)	2.57 (0.90)	2.16 (0.90)	2.45 (0.92)	2.50 (0.95)	2.37 (1.00)	2.69 (1.02)	3.05 (1.07)
External distraction												
Music	1.80 (0.82)	2.07 (0.88)	2.31 (1.11)	1.96 (0.94)	1.91 (0.85)	2.09 (0.95)	2.01 (0.90)	2.13 (1.05)	2.26 (1.03)	2.04 (1.02)	2.16 (1.00)	2.16 (1.16)
Silence	1.80 (0.86)	1.97 (0.91)	2.12 (1.08)	1.73 (0.65)	2.05 (0.94)	2.21 (1.08)	1.75 (0.70)	1.81 (0.93)	1.92 (0.93)	1.90 (0.89)	2.20 (0.93)	2.58 (1.09)

Note. Standard deviations are presented below the means in parentheses. RT = mean reaction time; RTCV = reaction time coefficient of variation (standard deviation of reaction time/mean reaction time); same = same trials; different = different trials. The variables of task focus, mind wandering, and external distraction were measured on a scale from 1 to 5.

[a] One participant in the easy group for sample one was excluded as they did not get any same trials correct. [b] Seven participants were excluded as RTCV could not be calculated due to low accuracy for same trials. Four participants were removed from the easy group (two from sample one and two from sample two), and three participants were removed from the hard group (all from sample two).

Task Performance

Hit Rate

Hit rate was calculated for each participant, for each time-on-task block, as the number of same trials correctly responded to divided by the total number of same trials (21). The assumption of homogeneity of variances was violated for the music condition at time two (p = .017) and the silence condition at time three (p = .026). There was a main effect of time-on-task, F(1.95, 399.44) = 12.10, MSE = 0.01, p < .001, η_p^2 = .06, with a significant linear trend such that hit rate declined over time, t(205) = 4.66, SE = 0.01, p < .001. There was also a main effect of task difficulty, F(1, 205) = 10.14, MSE = 0.23, p = .002, η_p^2 = .05, such that hit rate was lower in the easy group compared to the hard group. The main effects of listening condition and sample were non-significant, ps = .606 and .126 respectively, as were all interactions, ps ≥ .140.

False Alarm Rate

False alarm rate was calculated for each participant, for each time-on-task block, as the number of different trials incorrectly responded to divided by the total number of different trials (189). Homogeneity of variances was violated for all conditions (ps < .001). A visual inspection of the data showed that both the median and variance were larger for the hard group as compared to the easy group. There was a main effect of time-on-task, F(1.88, 385.68) = 4.41, MSE = 0.00, p = .014, η_p^2 = .02, with a significant quadratic trend, t(205) = 2.42, SE = 0.01, p = .017, such that false alarm rate decreased from time one to time two and increased from time two to time three. There was also a main effect of task difficulty, F(1, 205) = 89.85, MSE = 0.10, p < .001, η_p^2 = .31, such that false alarm rate was significantly higher in the hard group compared to the easy group. The main effects of listening condition and sample were non-significant, ps = .983 and .239 respectively, as were all interactions, ps ≥ .188.

Omission Rate

Omission rate—an index of behavioural disengagement (Cheyne et al., 2009)—was calculated for each participant, for each time-on-task block, as the number of omissions divided by the total number of trials (210). While omission rates were numerically higher under silence as compared to music, the main effect of listening condition was non-significant, $F(1, 205) = 3.86$, $MSE = 0.00$, $p = .051$, $\eta_p^2 = .02$. All other main effects were non-significant (ps ≥ .169). There was a significant listening condition by task difficulty interaction, $F(1, 205) = 6.38$, $MSE = 0.00$, $p = .012$, $\eta_p^2 = .03$. However, as omission rates were nearly at floor, we caution against any interpretation of this interaction. All other interactions were non-significant, ps ≥ .065.

Reaction Time

Both mean reaction time (RT) and reaction time variability (RTCV) were calculated for each participant, for each time-on-task block, for correct trials only. RT and RTCV were computed for same trials and different trials separately, as responses could be driven by different cognitive processes. For instance, same trials appeared much less often than different trials, and confirmation of rare events may require additional processes. We computed reaction time variability as the reaction time coefficient of variation, by dividing the standard deviation of reaction time by the mean reaction time. RTCV measures how much variability exists per unit of mean reaction time (Saville et al., 2011), and is an index of focal inattention (Cheyne et al., 2009).

Mean RT, Same Trials

One participant from sample one, in the easy group, was excluded from analyses as they did not respond correctly on any same trials in at least one time-on-task block. RTs were significantly longer for sample one compared to sample two, $F(1, 204) = 7.79$, $MSE = 30968.41$, $p = .006$, $\eta_p^2 = .04$. All other main effects were non-significant, ps ≥ .205. There was a significant task difficulty by listening condition by time-on-task interaction, $F(1.99, 406.28) = 4.41$, $MSE = 1966.38$, $p = .013$, $\eta_p^2 = .02$. To investigate this interaction, we conducted separate repeated measures ANOVAs for each task difficulty group, with listening condition and time-on-task as within-participants factors. For the easy group, there were no main effects, *p*s ≥ .672, and the interaction was non-significant, *p* = .058. For the hard group, there were also no main effects, *p*s ≥ .431, and the interaction was non-significant, *p* = .191. All other interactions in the omnibus ANOVA were non-significant, *p*s ≥ .317.

Mean RT, Different Trials

Homogeneity of variance was violated for the music condition at time two, *p* = .038, and the silence condition at times two and three, *p*s = .024 and .007 respectively. There was a main effect of time-on-task, $F(1.85, 380.08) = 18.50$, $MSE = 1721.02$, $p < .001$, $\eta_p^2 = .08$, with a linear trend such that RT declined over time, $t(205) = 5.39$, $SE = 3.11$, $p < .001$. There was also a main effect of task difficulty, $F(1, 205) = 24.03$, $MSE = 36709.38$, $p < .001$, $\eta_p^2 = .11$, such that RT was higher in the hard group compared to the easy group. As well, there was a main effect of sample, $F(1, 205) = 4.47$, $MSE = 36709.38$, $p = .036$, $\eta_p^2 = .02$, such that RT was higher for sample one compared with sample two. The main effect of listening condition was non-significant, *p* = .475, as were all interactions, *p*s ≥ .125.

RTCV, Same Trials

Seven participants were removed from the following analyses, as RTCV could not be calculated for at least one time-on-task block due to low accuracy for same trials (hit rate). Four participants were removed from the easy group (two from sample one and two from sample two), and three participants were removed from the hard group (all from sample two). There was a main effect of time-on-task, $F(1.57, 310.88) = 8.38$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .04$, with a significant quadratic trend, $t(198) = 3.99$, $SE = 0.01$, $p < .001$, such that RTCV declined from time one to time two and increased from time two to time three. There was a main effect of sample, $F(1, 198) = 5.24$, $MSE = 0.04$, $p = .023$, $\eta_p^2 = .03$, such that RTCV was lower for sample one compared to sample two. There was a main effect of listening condition, $F(1, 198) = 5.77$, $MSE = 0.01$, $p = .017$, $\eta_p^2 = .03$, such that RTCV was lower under music compared to silence. While RTCV was numerically lower for the easy group compared to the hard group, the main effect of task difficulty was non-significant, F(1, 198) = 3.37, *MSE* = 0.04, p = .068, η_p^2 = .02. All interactions were non-significant, *p*s = .253.

RTCV, Different Trials

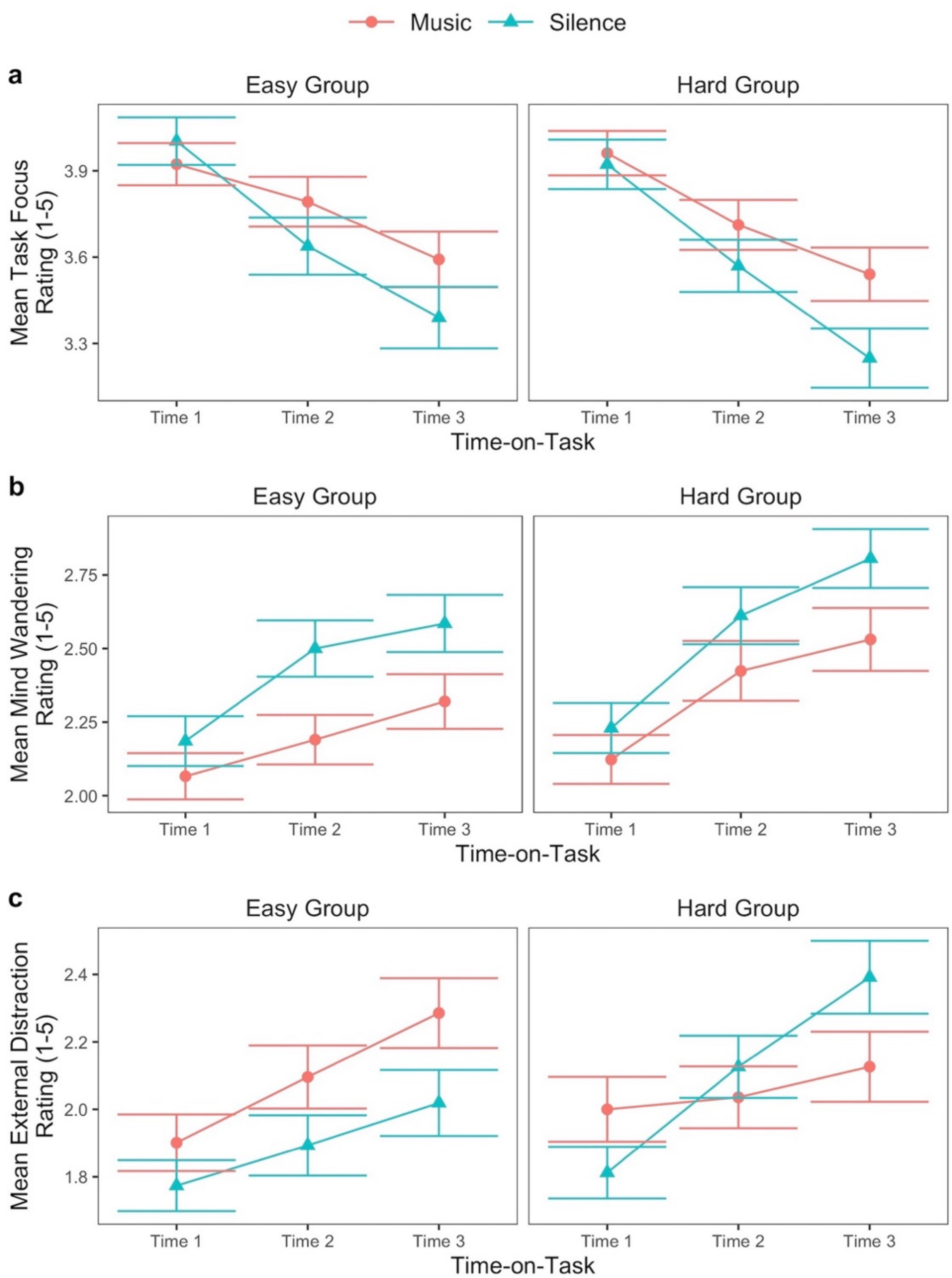
There was a main effect of sample, *F*(1, 205) = 4.34, *MSE* = 0.05, *p* = .038, η_p^2 = .02, such that RTCV was lower for sample one compared with sample two. There was a main effect of listening condition, *F*(1, 205) = 4.60, *MSE* = 0.01, *p* = .033, η_p^2 = .02, such that RTCV was lower under music compared to silence. All other main effects and interactions were non-significant, *p*s ≥ .334 and .095 respectively.

Task Engagement

For each task engagement measure (task focus, mind wandering, and external distraction/bodily sensation states), we computed the mean score (of three probes) for each participant, for each time-on-task block. See Figure 2 for graphical representations of task engagement as a function of listening condition, task difficulty group, and time-on-task, collapsed across samples.

Figure 2

Task Engagement as a Function of Listening Condition (Silence or Music), Time-on-Task (Three Blocks), and Task Difficulty (Easy or Hard)



Note. Error bars represent standard error of the mean. Means are collapsed across the between-participants factor of sample (sample one and sample two). Easy group, $n = 106$; Hard group, $n = 103$. Plots were created with ggplot2 (Wickham, 2016).

Task Focus States

There was a main effect of listening condition, $F(1, 205) = 5.41$, $MSE = 0.91$, $p = .021$, $\eta_p^2 = .03$, such that task focus states were higher under music as compared to silence. There was also a main effect of time-on-task, $F(1.75, 358.68) = 108.87$, $MSE = 0.29$, $p < .001$, $\eta_p^2 = .35$, with task focus states decreasing over time. The main effects of task difficulty and sample were non-significant, *p*s = .528 and .505 respectively.

There was a listening condition by time-on-task interaction, $F(1.82, 373.92) = 8.52$, $MSE = 0.24$, $p < .001$, $\eta_p^2 = .04$. Task focus states decreased over time for both listening conditions, with significant linear trends of time-on-task for both music, $t(205) = 7.31$, $SE = 0.05$, $p < .001$, and silence conditions, $t(205) = 11.17$, $SE = 0.06$, $p < .001$. The interaction between linear contrasts was significant, $t(205) = 3.59$, $SE = 0.07$, $p < .001$, and task focus states declined to a greater extent over time in the silence condition than in the music condition (see Figure 2A).

There was a sample by listening condition by time-on-task interaction, $F(1.82, 373.92) = 3.42$, $MSE = 0.24$, $p = .038$, $\eta_p^2 = .02$. To investigate the interaction, separate repeated measures ANOVAs were conducted for each sample, with listening condition and time-on-task as within-participants factors. For sample one, there was a main effect of time-on-task, $F(1.79, 186.04) = 60.67$, $MSE = 0.24$, $p < .001$, $\eta_p^2 = .37$, and a time-on-task by listening condition interaction, $F(1.90, 197.46) = 10.55$, $MSE = 0.24$, $p < .001$, $\eta_p^2 = .09$. The main effect of listening condition was non-significant, $p = .128$. There were significant linear trends of time-on-task for both music, $t(104) = 4.14$, $SE = 0.07$, $p < .001$, and silence conditions, $t(104) = 9.71$, $SE = 0.07$, $p < .001$, as well as a significant quadratic trend for the silence condition only, $t(104) = 2.21$, $SE = 0.10$, $p = .030$. Task focus states decreased over time for both listening conditions, but the interaction between linear contrasts was significant, $t(104) = 3.92$, $SE = 0.10$, $p < .001$, such that task focus states dropped over time to a greater extent in the silence condition. For sample two, there was a main effect of time-on-task, $F(1.68, 173.20) = 50.23$, $MSE = 0.34$, $p < .001$, $\eta_p^2 = .33$. The main effect of listening condition and the time-on-task by listening condition interaction were non-significant, *p*s = .086 and .262 respectively. Due to the significant listening condition by time-on-task interaction in the omnibus ANOVA when collapsed across sample, we computed linear contrasts for each listening condition separately, as well as the interaction between linear contrasts. There were significant linear trends of time-on-task for both music, $t(103) = 6.15$, $SE = 0.07$, $p < .001$, and silence conditions, $t(103) = 6.58$, $SE = 0.09$, $p < .001$, such that task focus states decreased over time for both conditions. The interaction between linear contrasts was non-significant, $t(103) = 1.25$, $SE = 0.11$, $p = .213$.

All other interactions in the omnibus mixed ANOVA were non-significant, *p*s ≥ .265.

Mind Wandering States

Homogeneity of variances was violated for the silence condition at time one, $p = .013$. There was a main effect of listening condition, $F(1, 205) = 14.14$, $MSE = 0.99$, $p < .001$, $\eta_p^2 = .07$, such that mind wandering was higher during silence as compared to music. There was also a main effect of time-on-task, $F(1.75, 359.01) = 55.57$, $MSE = 0.38$, $p < .001$, $\eta_p^2 = .21$, such that mind wandering increased over time. Main effects of task difficulty and sample were non-significant, *p*s = .145 and .340 respectively.

There was a three-way, sample by task difficulty by time-on-task, interaction, $F(1.75, 359.01) = 3.87$, $MSE = 0.38$, $p = .027$, $\eta_p^2 = .02$. Separate mixed ANOVAs were conducted for each sample, with time-on-task and task difficulty as within- and between-participants factors respectively. For sample one, there was a main effect of time-on-task, $F(1.80, 185.11) = 28.33$, $MSE = 0.17$, $p < .001$, $\eta_p^2 = .22$. There were significant linear, $t(103) = 6.25$, SE = 0.06, $p < .001$, and quadratic trends, $t(103) = 2.61$, $SE = 0.08$, $p = .010$, and mind wandering increased over time. The main effect of task difficulty and the two-way interaction were non-significant, *p*s = .878 and .310 respectively. For sample two, there was a main effect of time-on-task, $F(1.70, 173.91) = 27.64$, $MSE = 0.21$, $p < .001$, $\eta_p^2 = .21$. There was a main effect of task difficulty, $F(1, 102) = 4.74$, $MSE = 1.65$, $p = .032$, $\eta_p^2 = .04$, such that mind wandering was higher for the hard group as compared to the easy group. There was also a significant task difficulty by time-on-task interaction, $F(1.70, 173.91) = 4.74$, $MSE = 0.21$, $p = .014$, $\eta_p^2 = .04$, with significant linear trends of time-on-task for both the easy, $t(102) = 2.63$, $SE = 0.10$, $p = .010$, and the hard group, $t(102) = 6.15$, $SE = 0.10$, $p < .001$, such that mind wandering increased over time for both groups. The interaction between linear contrasts was significant, $t(102) = 2.55$, $SE = 0.14$, $p = .012$, indicating that mind wandering increased to a greater extent over time for the hard group than the easy group.

In the omnibus ANOVA, the listening condition by time-on-task interaction was non-significant, $F(1.90, 389.25) = 3.00$, $MSE = 0.26$, $p = .054$, $\eta_p^2 = .01$, however, there appeared to be a trend toward mind wandering increasing more over time in the silence condition. Mind wandering increased over time in both listening conditions, with significant linear trends of time-on-task for both music, $t(205) = 5.97$, $SE = 0.06$, $p < .001$, and silence conditions, $t(205) = 7.56$, $SE = 0.06$, $p < .001$. There was also a significant quadratic trend for the silence condition, $t(205) = 2.49$, $SE = 0.08$, $p = .014$. The interaction between linear contrasts was significant, $t(205) = 2.05$, $SE = 0.08$, $p = .042$, such that mind wandering increased to a greater extent over time in the silence condition than in the music condition (see Figure 2B).

All other interactions in the omnibus ANOVA were non-significant, *p*s ≥ .095.

External Distraction and Bodily Sensation States

There was a main effect of time-on-task, $F(1.62, 332.45) = 32.52$, $MSE = 0.44$, $p < .001$, $\eta_p^2 = .14$, such that external distraction/bodily sensation states increased over time. All other main effects were non-significant, *p*s ≥ .217. There was a significant task difficulty by listening condition interaction, $F(1, 205) = 4.94$, $MSE = 1.04$, $p = .027$, $\eta_p^2 = .02$, as well as a significant task difficulty by listening condition by time-on-task interaction, $F(1.76, 361.57) = 8.42$, $MSE = 0.31$, $p < .001$, $\eta_p^2 = .04$. To explore the interactions, we conducted separate repeated measures ANOVAs for each task difficulty group with listening condition and time-on-task as within-participants factors (see Figure 2C). For the easy group, there was a main effect of listening condition, $F(1, 105) = 6.02$, $MSE = 1.04$, $p = .016$, $\eta_p^2 = .05$, such that external distraction/bodily sensation states were higher under music as compared to silence. There was a main effect of time-on-task, $F(1.73, 181.67) = 15.50$, $MSE = 0.39$, $p < .001$, $\eta_p^2 = .13$, with a significant linear trend, $t(205) = 6.65$, $SE = 0.05$, $p < .001$, such that external distraction/bodily sensation states increased over time. The listening condition by time-on-task interaction was non-significant, $p = .364$. For the hard group, the main effect of time-on-task was significant, $F(1.50, 152.74) = 16.92$, $MSE = 0.51$, $p < .001$, $\eta_p^2 = .14$, the main effect of listening condition was non-significant, $p = .493$, and there was a significant listening condition by time-on-task interaction, $F(1.78, 181.26) = 9.13$, $MSE = 0.33$, $p < .001$, $\eta_p^2 = .08$. Separate repeated measures ANOVAs with time-on-task for each listening condition revealed that for the silence condition, the main effect of time-on-task was significant, $F(1.58, 161.37) = 22.74$, $MSE = 0.48$, $p < .001$, $\eta_p^2 = .18$, with a significant linear trend, $t(102) = 5.56$, $SE = 0.10$, $p < .001$, such that external distraction states increased over time. The main effect of time-on-task was non-significant for the music group, $p = .229$. All other interactions in the omnibus ANOVA were non-significant, ps $\geq .098$.

Listening Habits

Although not relevant to our main research questions, for the sake of completion, we present self-reported frequencies by which participants generally listen to music while performing attention-demanding tasks in Table 2.

Table 2

Frequencies by Which Participants Listen to Music While Performing Attention-Demanding Tasks

Sample and task difficulty group	Listening frequency									
	Never		Rarely		Sometimes		Often		Always	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Sample one										
Easy group (*n* = 53)	5	9.4	9	17.0	14	26.4	18	34.0	7	13.2
Hard group (*n* = 52)	6	11.5	13	25.0	12	23.1	17	32.7	4	7.7
Sample two										
Easy group (*n* = 53)	1	1.9	4	7.5	15	28.3	25	47.2	8	15.1
Hard group (*n* = 51)	0	0.0	6	11.8	15	29.4	24	47.1	6	11.8

Discussion

Across two samples, we examined how listening to self-selected background music, compared to silence, affects performance on a vigilance task as well as subjective experiences of task engagement. To ascertain a more complete understanding of these relations, we also explored how they may vary as a function of task difficulty and time-on-task. Our methodology had two significant advantages over prior research (Kiss & Linnell, 2021). First, our approach to measuring task engagement allowed participants to report varying degrees of different attentional states simultaneously, enabling us to capture the inherent complexities of the subjective attentional experience. Secondly, our sample was not limited to individuals who frequently listen to music while performing attention-demanding tasks, thus improving the generalizability of our findings and allowing us to investigate the representativeness of previous research. The current study found that for both task difficulty conditions, the addition of background music increased subjective task engagement and lowered reaction time variability, a known behavioural marker of inattention (Cheyne et al., 2009). Another important finding was that task engagement declined to a lesser extent over time when music was played than when it was not.

Perhaps the most striking outcome is that our results did not support our prediction that listening to self-selected music would facilitate task performance and increase ratings of task focus for an easy task but hinder task performance and decrease ratings of task focus for a hard task. Instead, regardless of task difficulty, task focus states were higher, mind wandering states were lower, and reaction time variability was lower when participants completed the vigilance task in the presence of music than in silence. These results are consistent with prior work showing that, for an easy task, the proportion of task focus states were higher when the task was completed with music, and task focus states correlated with lower reaction times (Kiss & Linnell, 2021). What is surprising, however, is that task engagement and performance in our study remained higher in the music condition when the primary task was made significantly more difficult. This finding is contrary to previous studies demonstrating that music facilitates task performance when task demands are low (presumably by increasing arousal to an optimal level) but hinders performance when task demands are high (presumably by increasing arousal past an optimal level; Wang et al., 2015).

The absence of this anticipated task difficulty by listening condition interaction on either task performance or task focus states cannot be explained by a failure to effectively manipulate task difficulty in our study, as analyses of task performance measures provide evidence that our easy task was indeed less difficult than the hard task. Specifically, compared to the easy group, participants in the hard group had higher mean reaction times for “different” trials (trials in which the Gabor patches did not point in the same direction) and higher false alarm rates (the proportion of different trials incorrectly responded to). While hit rate (the proportion of "same” trials correctly responded to; same trials being those in which the Gabor patches pointed in the same direction) was generally higher for the hard group, this was to be expected as discriminating between same and different trials was more difficult in this group compared to the easy group. That is, the difference in orientation between Gabor patches on different trials was much smaller. Thus, participants in the hard group might have demonstrated a greater bias towards endorsing a given trial as “same.” Supporting this notion are the higher false alarm rates in the hard group than in the easy group. Nevertheless, it may be that the task difficulty manipulation was not drastic enough to push difficulty into the right (overstimulated) range of the arousal curve. Future research could examine the influence of music on task performance and engagement at even higher levels of task difficulty.

There may be other reasons why we did not observe the predicted interaction between music presence and task difficulty on attentional engagement and performance. One possible explanation might relate to the nature of our task context and the way difficulty was manipulated in that context. To clarify, prior work that showed an interaction between music presence and task difficulty for task performance used a driving simulator task and manipulated difficulty by modifying the complexity of the driving environment (Wang et al., 2015). In our case, we used a perceptual discrimination task and increased task difficulty by decreasing the discriminability between Gabor patches for different trials. Compared to the driving simulator task, our task likely relied much less on cognitive mechanisms such as working memory or executive functioning for both difficulty groups, as it required simple perceptual discrimination decisions. Perhaps we would have observed a listening condition by task difficulty interaction if we had manipulated difficulty in a different way, particularly by choosing a hard task that recruits more cognitive processes such as working memory or executive functioning (as opposed to the greater recruitment of perceptual processes) than the easy task. For instance, one could increase working memory demands by implementing a successive discrimination task (i.e., deciding if the Gabor patch in a previous trial is the same orientation as the Gabor patch in the current trial, with a delay between Gabor patches).

Our second hypothesis, which was that there would be no listening condition by time-on-task interaction on either task performance or task engagement, was only partially supported. We found no strong interaction between music listening condition and time-on-task for most of our performance metrics (except mean reaction time for same trials, although we caution against interpretation of that interaction as accuracy for same trials was generally low). These findings are consistent with the heterogeneity of prior results in the literature: recall that some work suggests that adding music does not have an effect on performance and engagement over time-on-task (Burkhard et al., 2018; Kiss & Linnell, 2021) while other work suggests that background music mitigates the traditional vigilance decrement to performance (Davies et al., 1973; Fontaine & Schwalm, 1979). However, one unanticipated finding was that we found a protective effect of music against the decline in subjective task engagement over time; specifically, we found that task focus declined, and mind wandering increased to a lesser extent over time when music was present than when it was absent. Similarly, external distraction/bodily sensation states increased to a lesser extent over time for the hard group when participants listened to music than when they did not. However, we note that when we analyzed our second sample separately, the listening condition by time-on-task interaction for task focus data was non-significant, highlighting that this effect for task focus states might not replicate in smaller samples, perhaps due to sample variation.

Assuming our finding that the presence of music mitigates declines in subjective task engagement over time is sufficiently robust and replicable, it complements prior research showing that background music mitigates the traditional vigilance decrement to performance (Davies et al., 1973; Fontaine & Schwalm, 1979). These vigilance decrements are purposed to arise due to the monotonous nature of vigilance tasks, and task underload accounts of vigilance posit that these decrements are primarily due to disengagement from the task as opposed to a depletion of cognitive resources (Pattyn et al., 2008). Correspondingly, vigilance decrements to performance are usually accompanied by declines in subjective task engagement (e.g., increases in mind wandering; Thomson et al., 2015). There are some factors, however, that can lessen these performance deteriorations. For example, research shows that the vigilance performance decrement can be reduced by increasing motivation (Szalma & Hancock, 2006), increasing how engaging the task is (Pop et al., 2012), as well as by disrupting task monotony through breaks (Ralph et al., 2017). Self-selected background music may work in a similar way, with music working to engage the listener overall and subsequently benefiting task engagement over time.

Considering the influence of task difficulty on mind wandering more generally (regardless of listening condition), we found that mind wandering was numerically higher for the hard group than the easy group when the samples were combined and when sample two was considered separately. These findings are curious when compared to prior research, which generally shows that mind wandering decreases with increases in task difficulty (e.g., Smallwood et al., 2002, 2011; Thomson et al., 2013). Reduced mind wandering with increases in task difficulty is thought to occur since more attentional resources are required to complete harder tasks, leaving fewer resources to be directed towards task-unrelated thought for harder tasks (Smallwood & Schooler, 2006). However, there is reason to believe that mind wandering can increase when the task is made very hard, such as when reading complex texts (Feng et al., 2013). Mind wandering may increase in these contexts because there may not be enough cognitive resources available to properly complete the task, especially when other distractions are not minimized (McVay & Kane, 2010). When reading very complex texts, for instance, readers may lose track of the narrative and thus disengage from the text (see Feng et al., 2013). Thus, the relation between mind wandering and task difficulty is not necessarily linear: mind wandering might be highest when the task is too simple or too difficult, and lowest at more moderate difficulty levels. Thus, our easy and hard tasks may have invoked mind wandering for conceivably different reasons. For the easy task, fewer attentional resources may have been occupied, leaving a greater capacity for task unrelated thought. In contrast, the hard vigilance task may have discouraged participants from attempting to perform well, resulting in attentional decoupling.

One limitation of this study is that our sample skews female. This gender imbalance, however, might not be a substantial concern for the generalizability of our results since prior work does not reveal robust gender differences in attentional performance. For example, research examining whether gender is a reliable predictor of multitasking ability tends to yield inconsistent findings (e.g., Mäntylä, 2013; Stoet et al., 2013), and differences that appear to be due to gender may instead be explained by some tertiary factor that is related to gender, such as video game experience (Hambrick et al., 2010) or processing speed (Lui et al., 2021). Moreover, some studies have found no discernible gender differences in terms of everyday multitasking ability (Hirnstein et al., 2019; Strayer et al., 2013), as well as multitasking with background music more specifically (Turner et al., 1996). Thus, rather than investigating whether aptitude for multitasking with background music depends on gender, a fruitful direction of future work may be to explore whether theoretically meaningful individual difference factors that covary with both multitasking ability and gender influence the effect of background music on task engagement and performance.

The present findings suggest several additional avenues for future research. For instance, while we suspect that self-selected music increased arousal in comparison to silence in our study (which aligns with prior work; Cassidy & MacDonald, 2009; Ünal et al., 2013), it is possible that arousal did not increase substantially in the music condition. Future studies could address this possibility by employing direct measures of arousal when investigating the impact of self-selected background music on task performance and engagement. Relatedly, studies could employ pupillometry as an index of cortical arousal (locus coeruleus-norepinephrine system activation; Gilzenrat et al., 2010; Unsworth & Robison, 2016), along with other convergent measures (e.g., subjective arousal measures, heart rate, or galvanic skin response), to determine whether arousal does indeed mediate the relation between listening condition and task performance.

Statements and Declarations

Funding

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) through an NSERC Discovery Grant (RGPIN-2019-04071) awarded to author Daniel Smilek.

Competing Interest

The authors have no relevant financial or non-financial interests to disclose.

Data and/or Code Availability

All materials, experiment files, data, and statistical code can be found on the Open Science Framework (https://osf.io/n9w5m/).

Ethics Approval

Approval was obtained by the Office of Research Ethics at the University of Waterloo (Ethics approval number: 43377).

Consent to Participate

Informed consent was obtained from all individual participants included in the study.

Authors' Contribution

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Lauren A. Homann. The first draft of the manuscript was written by Lauren A. Homann and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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