Université de Montréal

Les effets émotionnels de la musique de fond sur l'attention sélective d'adultes

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Résumé

Les activités du quotidien peuvent souvent être effectuées en écoutant de la musique, ce qui pourrait influencer la capacité cognitive permettant de sélectionner les stimuli pertinents tout en ignorant les distracteurs (attention sélective). Des études antérieures ont établi que le niveau d'activation de la musique (p. ex. son caractère relaxant vs stimulant) aurait l'habileté de moduler l'humeur, ce qui pourrait affecter les performances cognitives. Le but de ce projet était d'explorer l'effet de l'écoute de musique de fond relaxante et stimulante sur les capacités d'attention sélective. À cet effet, 46 adultes en bonne santé ont réalisé une tâche de type Stroop dans différents environnements sonores : musique relaxante, bruits associés aux musiques relaxantes, musique stimulante, bruits associés aux musiques stimulantes, silence. Les résultats ont montré que le temps de réponse pour les essais incongruents et congruents et la mesure d'interférence du Stroop sont similaires dans toutes les conditions. De façon intéressante, les résultats ont révélé un taux d'erreur plus élevé pour les essais congruents lors de l'écoute de bruits associés à la musique relaxante par rapport à la musique relaxante. Une tendance similaire est également présente entre les bruits associés à la musique stimulante et la musique relaxante. Dans l'ensemble, ces résultats suggèrent que le silence et la musique de fond ont des effets sur les capacités d'attention sélective de l'adulte, alors que le bruit semble avoir un effet néfaste, spécifiquement lorsque la tâche est cognitivement plus facile. En conclusion, le type d'environnement sonore semble être un facteur qui peut affecter la performance des tâches cognitives plus que le niveau d'activation.

Mots-clés : attention sélective, inhibition, tâche de Stroop, musique de fond, émotions musicales, bruits de fond, niveau d'activation, neuropsychologie clinique.

Abstract

The daily activities can often be performed while listening to music, which could influence the ability to select relevant stimuli while ignoring distractors. Previous studies have established that music's arousal (e.g., relaxing/stimulating) have the ability to modulate mood and affect the performance of cognitive tasks. The aim of this research was to explore the effect of relaxing and stimulating background music on selective attention. To this aim, 46 healthy adults performed a Stroop task in different sound environments: relaxing music, noise-matched relaxing music, stimulating music, noise-matched stimulating music, and silence. Results showed that response time for incongruent and congruent trials and the Stroop interference effect are similar across conditions. Interestingly, results revealed more error rate for congruent trials in noise-matched relaxing music as compared to relaxing music, and a similar tendency between noise-matched stimulating music and relaxing music. Taken together, these results suggest that silence and background music have similar effects on adult's selective attention capacities, and noise seems to have a detrimental impact, specifically when the task is cognitively easier. In conclusion, the type of sound environment seems to be a factor that can affect cognitive tasks performance more than arousal.

Keywords: selective attention, inhibition, Stroop task, background music, musical emotions, background noise, arousal, clinical neuropsychology.

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BAI: Beck anxiety inventory

BDI: Beck depression inventory

bpm: beat per minute

BRAMS: Laboratoire international de recherche sur le cerveau, le son et la musique

CA: Californie

cm: centermeter

cong.: congruent

CRBLM: Centre de recherche sur le cerveau, le langage et la musique

dB: decibel

df: degree of freedom

e.g.: exempli gratia

ER: error rate

et al.: et alia

etc.: et cetera

i.e.: id est

IFPI: International Federation of the Phonographic Industry

Inc.: Incorporated

Incong.: incongruent

MA: Massachusetts

M: mean

MBEA: Montreal Battery of Evaluation of Amusia

min.: minutes

ms: milliseconds

MUSEC: Laboratoire de recherche en musique, émotions et cognition

NRM: noise-matched relaxing music

NSM: noise-matched stimulating music

RM: relaxing music

RT: response time

S: silence

sec.: seconds

SPL: sound pressure level

SM: stimulating music

USA: United Sates of America

Avec l'expression de ma profonde reconnaissance, je dédie ce modeste travail à ceux qui, quels que soient les termes embrassés, je n'arriverais jamais à leur exprimer mon amour sincère.

- *À mes parents, à qui je dois ma réussite et tout mon respect : Louis et Marie. Aucune dédicace ne saurait exprimer ma reconnaissance pour les sacrifices que vous avez consentis pour mon éducation.*
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- *Ce futur enfant qui naitra bientôt.*

« Et puis il y a ceux que l'on croise, que l'on connait à peine,

Qui vous disent un mot, une phrase, vous accordent une minute, une demi-heure,

Et changent le cours de votre vie » Victor Hugo

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Introduction

L'article de recherche rédigé dans le cadre de la présente étude sera présenté dans la prochaine section. Il sera soumis à la revue *Frontiers in psychology* en tant que court rapport de recherche dans un numéro spécial : « *Active Cognitive Processing for Auditory Perception* ».

Les effets émotionnels de la musique de fond sur l'attention sélective d'adultes

Cette recherche a été financée par les Fonds de recherche en santé du Québec (FRSQ), les Fonds de recherche du Québec – Société et culture (FRQSC), le Centre de recherche sur le cerveau, le langage et la musique (CRBLM). Le CRBLM est financé par les Fonds de recherche du Québec – Nature et technologie (FRQNT) et les FRQSC.

Introduction

Music is considered among the most enjoyable and satisfying human activities (Dubé & Le Bel, 2003). The recent development of portable players with unlimited access to musical libraries means that people's access to music has never been greater than in the last decade (Krause et al., 2014). Adults listened to music for an average time of 17.8 hours per week [International Federation of the Phonographic Industry (IFPI), 2018]. It is therefore possible to infer that most adults perform a large part of their daily tasks in the presence of background music (e.g., while cooking, driving, working, studying, etc.). The efficient accomplishment of these tasks recruits the capacities of selective attention, also referred as attentional control; the cognitive ability to select, among a considerable load of information, relevant stimuli while inhibiting others (Murphy et al., 2016; Bater & Jordan, 2020). These abilities therefore encompass the processes necessary to maintain the purpose of tasks under constrained circumstances, such as distractions (e.g., the presence of background music or noise) and interference (Shenhav, Botvinick, & Cohen, 2013). Two major processes therefore operate simultaneously, facilitation (or selection) and inhibition (van Moorselaar & Slagter, 2020). Focusing is the process of directing our awareness on relevant stimuli, while inhibition makes it possible to ignore stimuli irrelevant to the task (Noonan et al., 2018). The terms "selective attention" will be used in this text in order to refer as much to the process of focusing, as of inhibition, present in attentional control.

Several experimental tasks have been created to measure different aspects of attention. Some measure more the capacities of locating targets (cuing), searching for stimuli among others, or filtering (Yiend & Mathews, 2005). Among these tasks, those measuring filtering capacity involve the presentation of targets and distractors, which make it possible to test the ability of participants to select or ignore what is presented (Yiend & Mathews, 2005). The Stroop task is a central experimental paradigm used to probe cognitive control by measuring the ability of participants to selectively attend to task-relevant information and inhibit automatic task-irrelevant responses (Kalanthroff et al., 2018). In this task, participants need to identify the ink color of color names as quickly as possible (e.g., GREEN; RED; GREEN; RED). When the ink color and the word are incongruent (e.g., the word RED written in green ink), there is an interference effect. When the ink color and the word are congruent (e.g., the word RED written in red ink), there is a facilitating effect. In the literature, the magnitude of the Stroop interference measure (that is, the difference in response time and error rates it takes for an individual to process incongruous versus congruent trials), is commonly considered a measure of selective attention, of the functioning of the executive system, or the ability to inhibit automatic response (Maquestiaux, 2013). Indeed, one of the particularities of this task is that the participants must inhibit their automatic reading processes, in order to identify the ink of the words rather than the word itself (MacLeod, 2005).

Due to its front-line role in information processing, selective attention capacities represent the gateway to other executives and memory functions, the latter allowing us to adapt to the demands of daily life (Nobre et al., 2014; Cohen, 2011). According to the preceding definitions, the presence of inattention would cause the processing of information not relevant to the accomplishment of a task, at the expense of important information; this causing a deleterious effect on overall cognitive performance (Baldwin, 2012). Therefore, with a growing body of research showing the presence of background music influencing cognitive functioning (for review, see Kämpfe et al., 2010), it is important to better understand the influence of background music on selective attention. Particularly, since it could make it possible to formulate recommendations in order to optimize efficient performance on a daily basis.

Research investigating the effects of background music on selective attention performance has shown mixed results; sometimes showing neutral (Cloutier et al., 2020; Deng & Wu, 2020; Speer, 2011; Petrucelli, 1987; Cassidy & Macdonald, 2007; Wallace, 2010), beneficial (Amezcua et al., 2005; Darrow et al., 2006; Masataka & Perlovsky, 2013; Slevc et al., 2013; Cassidy & Macdonald, 2007; Fernandez et al., 2019), or deleterious (Deng & Wu, 2020; Masataka & Perlovsky, 2013; Slevc et al., 2013; Cloutier et al., 2020; Fernandez et al., 2019) effects on performance. However, according to summary work on the issue, multiple factors can influence this variability, for example, methodological limits are observed within this literature (Kämpfe et al., 2011; Schellenberg & Weiss, 2013). Several studies present small samples of adult participants, making it difficult to generalize the results to the general adult population (≤ 24 adult participants; Fernandez et al., 2019; Speer, 2011; Amezcua et al., 2005; Cloutier et al., 2020;

Giannouli, 2012). In addition, most of the time, non-auditory (e.g., silence) and auditory (e.g., noises with sound characteristics similar to music) control conditions were lacking (Darrow, 2006; Marchegiani & Fafoutis; 2019; Deng & Wu, 2020; Cloutier et al., 2020). There were also methodological limitations regarding the choice of the used sound material. Indeed, some studies have presented music with words (e.g., Darrow et al., 2006; Speer, 2011; Marchegiani & Fafoutis, 2019; Deng & Wu, 2020), which generally resulted in a deleterious effect on performance. However, several studies have previously shown that the presence of speech or words in a sound environment tends to negatively affect cognitive performance in comparison with a speechless sound environment (e.g., Salamé & Baddeley, 1989; Szalma & Hancock, 2011). The effect of language processing is therefore confused with the effect of background music in these studies. Another element that could explain the variability between the results of previous studies is the lack of control over the emotional characteristics of the sound stimuli being utilized (as discussed in Schellenberg & Weiss (2013) and Kämpfe et al. (2011)). Indeed, different sound environment can induce different emotions in the listener. Particularly for musical stimuli, musical parameters, such as tempo, can be modulated to induce different musical emotions, like the level of arousal (Gabrielsson & Juslin, 2003); music with fast tempi are usually considered as stimulating, while music with slow tempi are considered as relaxing (Bigand et al., 2005; Vieillard et al., 2008; Västjäll, 2001). The emotional characteristics of a sound environment, like its level of arousal, are important to consider as studies established links between them and performance on cognitive tasks (e.g., spatial skills, Thompson et al., 2001; selective attention, Ghimire et al., 2019). According to the arousal-mood hypothesis (Nantais et al., 2002; Nantais & Schellenberg, 1999; Schellenberg & Hallam, 2005; Schellenberg et al., 2007; Thompson et al., 2001; Thompson et al., 2011), cognitive performance can be promoted by sound stimulation increasing physiological activation and improving mood. Both music and noise can induce emotions (Hunter & Schellenberg, 2010), but music is particularly recognized for being able to induce positive emotions, and therefore positively modulate mood (Thompson et al., 2001). Thus, these researchers' results have shown that when participants listened to music that positively altered their mood before performing a cognitive task, their performance on it was improved. Research carried out on the subject has thus identified that two emotional characteristics of a stimulus could particularly affect performance, namely its level of arousal (referring to the relaxing vs. stimulating nature of a stimulus) and its valence (referring to the pleasant or unpleasant nature of a stimulus; Västfjäll, 2001). Thus, it is suggested that a sound environment judged to be stimulating and pleasant would be the ideal environment to optimize cognitive performance (Schellenberg & Weiss, 2013). This theory is based on listening to a stimulus before the accomplishment of a cognitive task. It is therefore interesting to ask whether the effects are the same when there is a simultaneous presence of a sound stimulus during the completion of the task.

Some studies have investigated it, for example, studies from Masataka & Perlovsky (2013) and Slevc (2013) obtained similar results showing that the Stroop performances were diminished in the presence of dissonant music (sounds whose union is unpleasant; possess an unpleasant valence) and increased with consonant music (sounds whose union is pleasant to hear; possess a pleasant valence). The results of these studies suggest that the valence of a stimulus can modulate attentional performance. In addition, the judgment of the valence can be influenced by the familiarity of the extract (referring to the known or unknown character of a stimulus). Indeed, some studies have shown that people tend to find a stimulus that they know (eg. a piece of music) more pleasant (Parente, 1976; van den Bosch et al., 2013; Schellenberg et al., 2008). Some authors even indicate that familiarity with a stimulus could have the power to increase the pleasure associated with the development of a task without compromising its performance (Feng & Bidelman, 2015; Pereira et al., 2011). In this regard, Darrow and colleagues (2006), Speer (2011), and Giannouli (2012) asked their participants to bring their favorite background music to perform a selective attention task. In these studies, the music selected by the participants held characteristics of high emotional valence and familiarity. However, the other characteristics of the music utilized were heterogeneous from one subject to another (e.g. style, complexity of the music pieces, presence of lyrics, or the level of arousal). The results of these studies indicate that participants consistently performed better in the familiar music conditions. Since we know little about the characteristics of the different pieces of music used in these studies and that a great variability is therefore present between them, it is difficult to identify whether the results are generalizable to listening to background music in general or whether they are specifically attributable to a modulation of mood and/or arousal due to the emotional characteristics and familiarity of the music used. Then, only a few studies have attempted to better understand the effect of music's arousal on the capacities of selective attention. In Cassidy and Macdonald (2007) study, the principles of the arousal-mood hypothesis (Thompson et al., 2001) have not been followed since valence and arousal were confused (comparing pleasant-relaxing and unpleasant-stimulating music). Finally, the studies of Amezcua et al. (2005), Cloutier et al. (2020) and Fernandez et al. (2019) have all investigated the effect of music's arousal on visual selective attention, but their results are difficult to generalize to the adult population due to their small sample size (respectively, 12, 21 and 19 participants).

The objective of this research project was to explore the effect of the arousal level of background music on adult's selective attention capacities. We compared the effect of stimulating and relaxing music on Stroop's task performance, with two music noise-matched conditions (stimulating music noise-matched and relaxing music noise-matched) and a silence condition as auditory and non-auditory controlled conditions, respectively. Based on the arousal-mood hypothesis (Thompson et al., 2001), we expect that the most stimulating and pleasant sound environments, the stimulating music condition, would be the one in which the Stroop interference measure and the error rate will be the lowest. This should be followed by the noise-matched stimulating music condition and the relaxing music condition, holding either a high arousal level or a high valence level. We expect that emotional characteristics such as low arousal level and low valence level of the noise-matched relaxing music condition should lead to higher interference score and error rate in this condition than during the absence of stimulation (silence condition).

Materials and methods

Participants

46 participants, including 31 university students and 15 workers were included in this study. Students and workers participants were matched for school level, years of musical learning and present a similar proportion of male and female (see **Table 1**). Although, students were found to be younger than workers (see **Table 1**). All participants were native French speakers, had normal hearing (measured by a brief hearing test done with an audiometer AC40 Interacoustics; participants had pure tone thresholds under 40 dB SPL; World Health Organization, 1980) and normal or corrected-to-normal vision. None of the participants had colour blindness or a history of neurological/psychiatric/neurodevelopmental disorders. None of them were taking drugs or medication that affected the central nervous system during the study. In addition, participants were excluded if they presented at least one of the following criteria: (i) music perception deficits (i.e., performance below 73% at the scale subtest, 70% at the off-beat subtest, and 68% at the out-of-key subtest of the online Montreal Battery of Evaluation of Amusia (MBEA; Peretz & Vuvan, 2017); (ii) presence of mood disorders, evaluated with the Beck Depression Inventory-II (BDI-II; Beck et al., 1996) and the Beck Anxiety Inventory (BAI; Beck et al., 1988) and (iii) musicians. Individuals were considered musicians if they completed equal to or more than five years of formal music lessons or were self-taught under that time frame in learning/practicing an instrument, and were practicing a musical instrument equal to or more than two hours per week (Zhang et al., 2020). The average number of years of musical training/practice of the participants (calculated by taking the number of years of formal music training added to the number of years of self-taught in learning or practicing an instrument) was 1.95 years ± 2. All participants gave their written informed consent in accordance with regulation of the local ethics committee at the University of Montreal.

Table 1

Demographic information and comparison between students and workers participants on demographic variables

	Total	Professional category		df	χ^2/t	p	Effect size (η^2)
		Students	Workers				
N (M, F)	46 (19, 27)	31 (11, 20)	15 (9, 6)	1	0.7	=0.40	=0.17
Age (years)	25.57 (4.33)	23.77 (3.38)	29.27 (3.73)	44	-4.99	<.001	=0.36
Years of education	17.1 (2.24)	17.05 (2.32)	16.77 (1.98)	44	0.4	=0.69	=0.00
Years of musical training	1.95 (2)	2.19 (1.91)	1.35 (1.8)	44	1.42	=0.16	=0.04

Note. Except for the sex variable, this table shows mean (and standard deviations) values. M = male, F = female. Students and workers groups were compared for sex, using a chi square test, and for age, years of education and years of musical training using independent t-tests.

Auditory materials

The 16 auditory stimuli encompassed eight music and eight acoustically matched noise. The eight musical stimuli (four highly pleasant and stimulant excerpts and four highly pleasant and relaxant excerpts) were selected from our lab database of 42 short instrumental classical music excerpts (30 000 ms), all in major mode. The selection was made based on valence (i.e., 0 = very unpleasant – 100 = very pleasant), arousal (i.e., 0 = very relaxing – 100 = very stimulating) and familiarity judgments (i.e., 0 = unknown – 100 = very familiar) obtained using visual analogue scales by 46 non-musicians (different participants that in our study; Nadon et al., 2016; for more information see **Supplementary material**).

Using data from Nadon et al. (2016), independent-samples t-tests revealed that excerpts in the relaxing condition differ significantly from the ones in the stimulating condition in terms of arousal (respectively, M = 11.73 ± 11.1, M = 79.18 ± 18.75; t(366) = -42, p < .001, η2 = .82) and familiarity (respectively, M = 44.35 ± 36.72, M = 91.35, ± 19.25; $t(366) = -15.38$, $p < .001$, $\eta 2 = .39$). No difference of valence was found between the relaxing and stimulating excerpts (respectively, M = 80.61 ± 18.72, M = 78.43 ± 21.11; $t(366) = -1.1$, $p = .3$, $\eta 2 = .01$. In order to present a consistent audio standard, only musical pieces of good quality and interpretations were used to create the musical stimuli (see **Supplementary material** for more information).

For auditory control conditions, acoustically matched noises were created based on the procedure used in previous research (Blood & Zatorre, 2001; Zatorre et al., 1994). The spectral envelope of each music stimulus was exported and applied to a synthesized white noise. This generated "noise melody" was different for each matched music stimuli. After testing the material with a few pilot participants, they told us that they were able to recognize the music associated with the noises if they had heard them before. Therefore, to ensure that participants would not recognize the rhythmic patterns from the matched music piece while listening to the noise-matched stimulus, each noise stimulus was recorded while played in reverse to create the final noise-matched stimulus.

The final 16 stimuli (i.e., eight musical excerpts and eight acoustically noise-matched excerpts) were normalized in amplitude, had a duration of 60 000 ms, with 1 000 ms fade-in and 2 000 fade-out. All above sound processing was performed using Adobe Audition 3.0 software (Adobe Systems Inc., San Jose, CA, USA).

Task

Participants performed the task in a soundproof room. Visual information was displayed on a computer monitor at a distance of 60 cm, while auditory information was presented binaurally using headphones (DT770 Pro, Beyerdynamic) at a sound level ranging approximately around 60 decibels. Participants had access to a keyboard and a mouse, all of which were connected to the computer (HP ProDesk 600 G1, Windows 7) outside the room, on which the task was run. Communication between inside and outside the soundproof room was done using microphones.

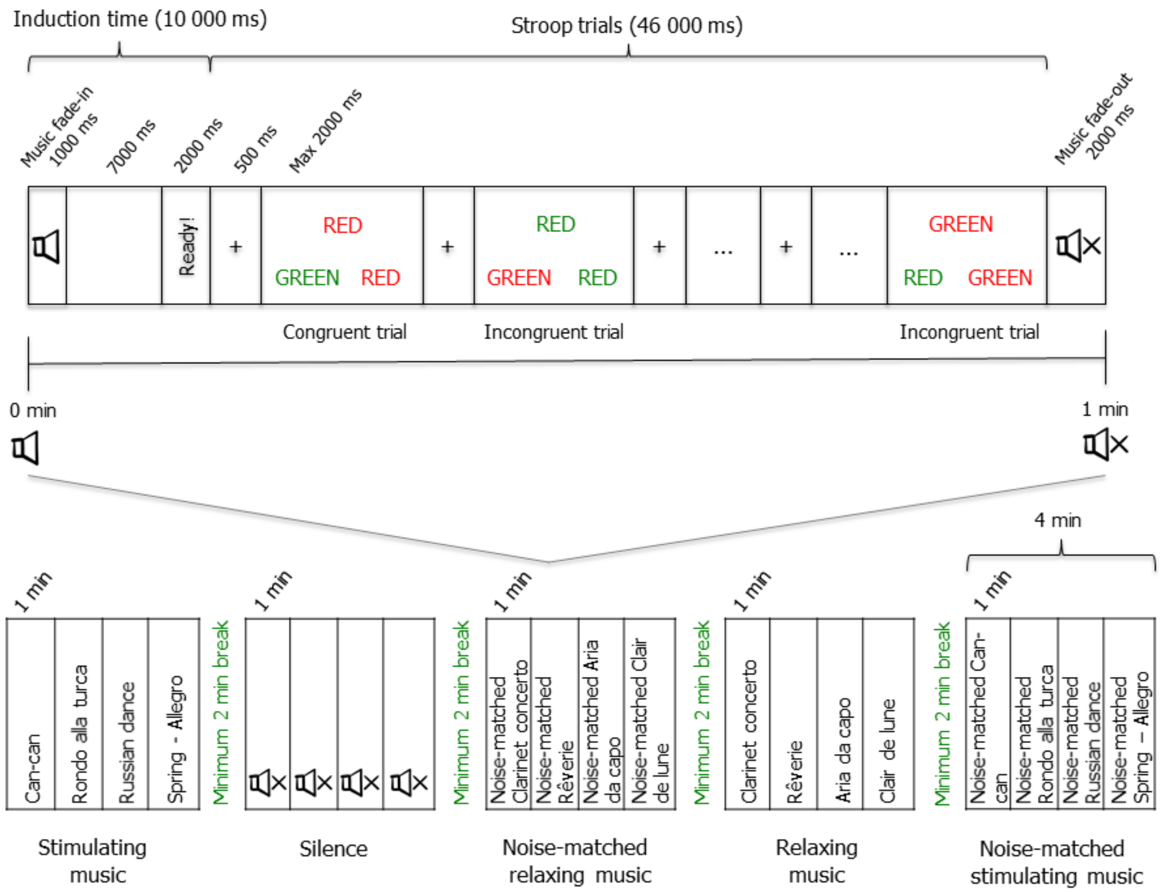
Selective attention was measured using a computerized Stroop-type task (Stroop, 1935; customized scripted and inspired by the Double trouble task from the *Cambridge Brain Sciences team*[1]). Each trial presented a target word (RED or GREEN) that appeared above two response words (RED and GREEN, see **Figure 1**). The color of the target word was either congruent (e.g., the word RED presented in red ink) or incongruent (e.g., the word RED presented in green ink) to the meaning of the word. To add a level of difficulty, when the trial was incongruent, the ink color in which the response words were presented was incongruent also. Participants therefore had to identify the ink color of the target word by selecting (with the keyboard arrows left and right) the correct response word below. The presentation of stimuli, and the recording of the type of stimuli presented, response time and accuracy, were carried out using the Psychtoolbox-3.0.13 (developed by Matlab and GNU Octave) implemented in Matlab 2015b (Mathworks Inc., Natick, MA, USA).

Participants were instructed to perform as many Stroop trials while being as accurate as possible before the end of the block. Each Stroop trial consisted of a fixation cross (presented 500 ms; see **Figure 1**) followed by one of the eight possible color-word stimulus options, presented in a pseudo-randomized order. Participants had a maximum of 2 000 ms to give their answer. If participants answered before this given time, another trial began and so on. Past this time, the trial ends, a missed trial is recorded, the words "Too late" appear on the screen (for 400 ms), and the next trial begins.

[1] See: www.cambridgebrainsciences.com/tests/double-trouble

Figure 1

Schematic representation of the experimental procedure and experimental Stroop block



Note. Participants were performing the five sound conditions in a counterbalanced order.

Procedure

Participants practiced performing the task in three blocks of 30 sec., with a possibility to take a break between the blocks in order to clarify instructions if needed. Each block was performed respectively in silence; accompanied by a music stimulus previously judged to have a neutral level of activation and high level of valence (see **Table S1**; Nadon et al., 2016), and with the noise-matched stimulus. Practice blocks were similar to experimental blocks, except that participants responded to Stroop trials for only 16 sec. During these practice blocks, participants received feedback for their answers (correct/incorrect; 800 ms). After completing the three practice blocks, participants could choose to receive the instructions specific to the experimental part, or to continue practicing (by performing all three blocks again).

For the experimental testing, participants performed the Stroop task in five sound conditions: Silence (S), relaxing music (RM), noise-matched relaxing music (NRM), stimulating music (SM), and noise-matched stimulating music (NSM; see **Figure 1**). The order in which participants performed the sound conditions was counterbalanced across participants and the order of presentation of musical or noise stimuli inside the same sound condition was pseudorandomized across participants using the Matlab script. Each sound condition consists of four consecutive blocks of 60 000 ms. Each block began with an induction phase (for 8 000 ms) presenting a blank screen while the participant either listened to the music or noise played, or remained in silence, depending on the sound condition that was performed (see **Figure 1**). Then, the word “Ready!” was presented (for 2 000 ms), followed by the beginning of a 46 000 ms sequence of Stroop task trials. Participants therefore performed their last Stroop trial just before the sound fade-out, when applicable. When participants completed a sound condition (total of 4 min.), they had to take a break of at least 2 min. during which they left the soundproof room to answer questionnaires, until they were asked to return to the room to perform the next condition.

After completing the task, participants were asked to listen to each auditory stimulus they heard during the task. Stimuli were presented in a randomized order and visual analogue scales were shown on the screen. Participants were asked to evaluate the level of valence (very unpleasant (0) to very pleasant (100)), arousal (very relaxing (0) to very stimulating (100)) and familiarity (unknown (0) to very familiar (100)) for each auditory stimulus.

Data analysis

Accuracy (error rate (ER); percentage of incorrect responses excluding missed trials) and mean response times (RT) of successful trials were computed for each participant, for each sound condition (i.e., RM, NRM, SM, NSM and S) and Stroop congruence trial type (i.e., congruent and incongruent). A trial was considered successful when the participant was accurate to indicate the ink colour of the target word within the imposed time limit (2 000 ms). Of these correct trials, a first mean and standard deviation were calculated, and only RT between -1.97 and 1.97 standard deviation from the participant's mean were used to calculate RT. The Stroop interference effect was calculated by subtracting mean RT of congruent from incongruent conditions (i.e., mean RT incong. – mean RT cong.) for each sound condition. Mean ER and RT were entered into separate repeated measures analyses of variance (ANOVAs) with Sound Conditions and Stroop Congruence trial type as within-subject factors. Mean Stroop interference scores were entered into another repeated measures ANOVA with Sound Conditions as within-subject factors. When interactions or a principal effect were significant, t-test analysis were performed.

Paired-sample t-tests were performed to evaluate differences between judgments of arousal, valence and familiarity for the musical stimuli and the noise-matched stimuli (see **Table S2**). Independent t-tests were also performed to evaluate differences between students and workers in terms of sex, age, years of education and years of musical training (see **Table 1**). All data were analyzed using IBM SPSS Statistics 26 (IBM Corp., 2019). The alpha levels were set at .05 for all analyses.

Results

Auditory stimuli evaluation

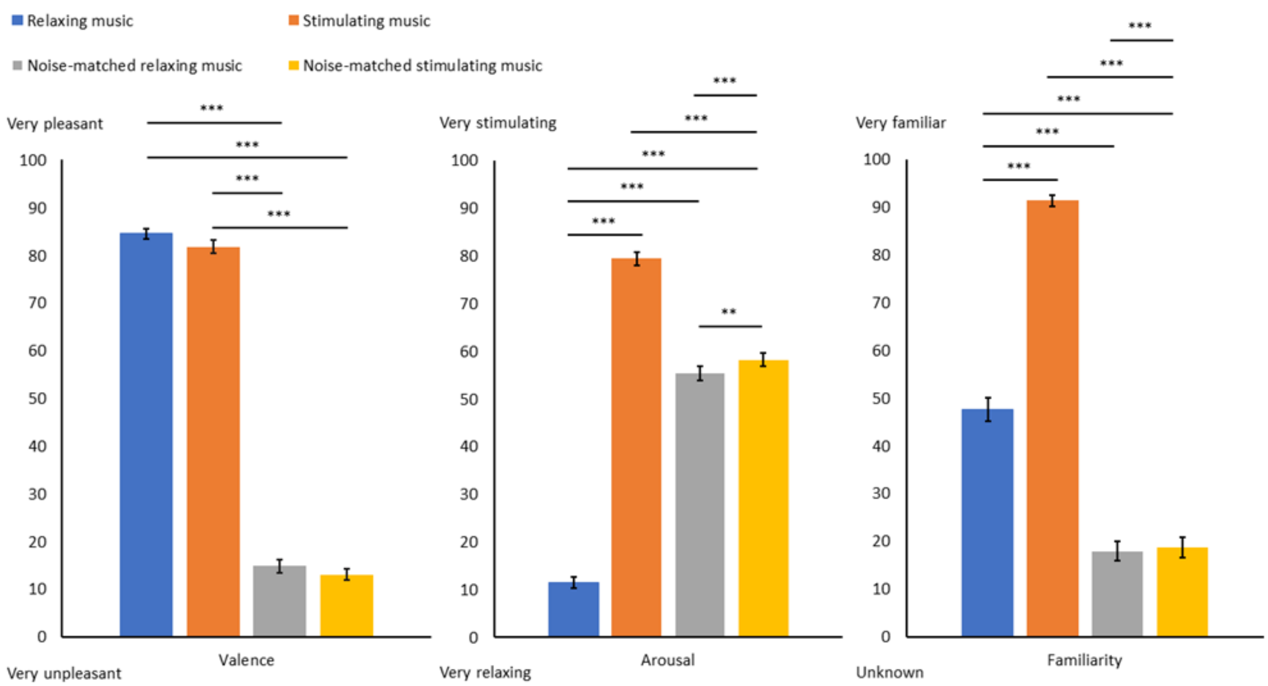
As expected, judgments of arousal from participants were significantly higher for the stimulating music (SM) compared to the relaxing music (RM). The arousal was judged significantly higher for the two noise conditions (NRM and NSM) compared to the RM. Similarly, the arousal was judged significantly lower for the two noise conditions (NRM and NSM) than for the SM. NSM was considered significantly more stimulating than NRM (see **Figure 2** and **Table S3** for details on arousal's results).

For the evaluation of valence, as expected, participants considered that the two music conditions (RM and SM) were significantly more pleasant than the two noise conditions (NRM and NSM). There was no significant difference between the two music conditions (RM and SM) and the two noise conditions (NRM and NSM) in terms of valence (see **Figure 2** and **Table S3** for details on valence's results).

The SM was significantly more familiar compared to the all other conditions, followed by the RM which was also significantly more familiar from the two noise conditions (NRM and NSM). There was no difference between the level of familiarity among the two noise conditions (NRM and NSM; see **Figure 2** and **Table S3** for more details).

Figure 2

Mean scores for the emotional judgments of valence and arousal and mean scores for the evaluation of familiarity for each sound condition



Notes. Graph shows standard errors.

$^{**}p < .01$.

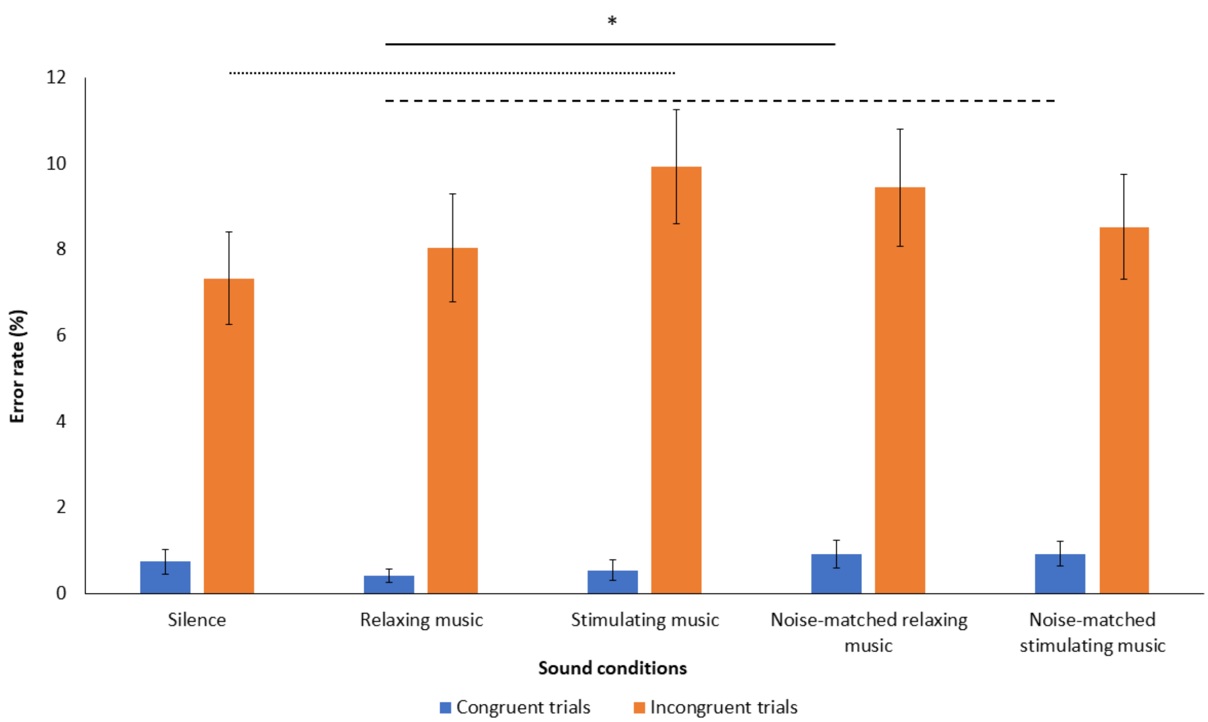
$^{***}p < .001$

Stroop task

The correct response time (RT) and error rate (ER) analyzes supported the observation of a Stroop interference effect as RTs were significantly longer and ERs were higher on incongruent trials compared to congruent trials (effect of congruence on response time: $F_{(1, 45)} = 253.93$, $p < .005$, $\eta^2 = .85$; effect of congruence on error rate: $F_{(1, 45)} = 104.158$, $p < .005$, $\eta^2 = .70$). In terms of RT on incongruent and congruent trials, there were no significant differences in performance between the different sound conditions ($F_{(1, 45)} = 1.01$, $p = .405$, $\eta^2 = .02$). In the analysis of ERs for incongruent and congruent trials in each sound condition, the ER for congruent trials in the NRM was significantly higher than in the RM condition ($t_{(45)} = 2.10$, $p < .05$, $\eta^2 = .09$). A similar tendency is noted between the ER for congruent trials in the NSM compared to the ER in RM ($t_{(45)} = 1.81$, $p = .077$, $\eta^2 = .07$). Regarding the ER for incongruent trials, there was a trend towards a higher ER in the SM condition compared to the silence condition ($t_{(45)} = -1.69$, $p = .097$, $\eta^2 = .06$, see **Figure 3** and **Table S4** for more details on Stroop's task results). No significant effect was found in the analysis with the interference scores for each sound condition ($F_{(1, 45)} = 0.394$, $p = .813$, $\eta^2 = .009$).

Figure 3

Mean error rate on incongruent and congruent trials for each sound condition



Notes. Graph shows standard errors.

*$p < .05$.

- - - - = p = .07.

…… = p = .09.

Based on the results obtained, simple regression analyzes were performed to determine whether it was possible to predict Stroop performance scores (response time and error rate in different regressions) based on emotional judgments scores (valence and arousal in different regressions). Multiple regression analyzes were also conducted to determine whether it was possible to predict Stroop performance scores (response time) based on emotional judgments scores (valence and arousal in together and separate regression) and the percentage of unsuccessful trials (as defined by erroneous trials + missed trials (2 000 ms trials in which the participant saw the instructions too late and could no longer respond). Results showed only a trend that was obtained during the simple regression that was calculated to predict the mean interference as a function of the valence judgments. A trend was noticed with the following equation ($F(1, 90) = 2.86$, $p = .094$), with an R^2 of 0.031. The mean interference prediction is 355.379 – 1.408 (valence) ms. According to the equation, the average participant interference would decrease by 1.408 for each valence score gained. However, when a multiple linear regression is performed including also the percentage of unsuccessful trials, the trend is no longer present.

No significant results are found when familiarity scores are included in linear regression models or analysis of covariance. In order to further investigate possible associations between emotional judgments of different sound conditions and performance measures, we performed correlation analyzes between scores of emotional judgments of valence, arousal and familiarity (separately) according to the different performance scores of response times and error rates for each sound condition (excluding silence since there is no emotional judgment score for this condition). The significant results obtained by these analyzes are presented in **Table S5**.

Discussion

The aim of this study was to investigate the effect of background music's arousal level on selective attention from adults. Based on the results, there did not appear to be any significant differences in attentional performance depending on whether the task was performed in silence, accompanied by relaxing music or stimulating music. Though the results showed that participants only seem to tend to make a greater number of errors when listening to stimulating music compared to silence, the result is not significant. However, when comparing on-task performance in the presence of music or noise, performance is more affected by the presence of noise given that there is a significant difference in error rate for congruent trials between relaxing music (RM) and noise-matched relaxing music (NRM), and a trend between relaxing music and noise-matched stimulating music (NSM).

These results are somewhat encouraging since they show that addition of cognitive information to be processed (e.g., background music) does not necessarily have deleterious effects on cognitive performance as some theories suggests. Indeed, according to the bottleneck/funnel models of attention conceptualized by Broadbent (1958, 1978, 1979, 1982) and Treisman (1964), we cannot consciously attend to all the input at the same time. Adding music or noises would therefore add a higher level of difficulty to the attentional process as the individual must not only perform the task (which is associated with an attentional cost) but must also inhibit auditory information (music or noises) which are not relevant to its accomplishment. According to this way of conceiving attention, music or noise should therefore necessarily have deleterious effects on performance, insofar as they consist in the addition of information to be processed or to a situation of dual attentional task. The principle of Kahneman's limited capacity model (1973) is similar to the models presented above. However, the difficulty of the task is taken into account. Thus, a task with a heavy cognitive load (difficult task; e.g. learning a new dance) would use more processing capacity than a task with a light cognitive load (easy or automatic task; e.g. walking). Even if it remains complex with this model to be able to determine the exact value of the cognitive load of a specific task, for example, the Stroop task (1935), it is theoretically possible to deduce that the cognitive load of automatic trials in this attentional task (i.e.

congruent trials) is probably smaller than the one of complex trials (i.e. incongruent trials). According to this model, it would be expected that the presence of noise or music during the accomplishment of that Stroop task has more harmful effects during the most difficult trials (i.e. incongruent), as well as accompanied by sound environments with greater cognitive load (e.g. influenced by the type of sound environment, its intensity (amplitude), frequency of the sound waves (intermittency per se), presence of speech, etc.; Szalma & Hancock, 2011; Kahneman, 1973). Since no difference was found between performance in silence and performance accompanied by auditory stimuli (music or noise), we can infer that the processing of auditory stimuli as used in this project does not lead to a dual task situation as predicted by Broadbent (1958, 1978, 1979, 1982) and Treisman (1964) models. The results of this study are also not congruent with Kahneman's model hypothesis since although there is, as expected, an interference effect in each condition, the sound environments with a greater cognitive load (stimulating music and associated noise) did not lead to a poorer performance for incongruent trials as compared to congruent trials. Rather, there was an opposite effect where noises had adverse effects only on congruent trials.

With the results of this study, it is therefore possible to assume that performing many of our daily tasks in the presence of instrumental music should not have a negative effect on the level of selective attention demand in order to perform these optimally.

According to the arousal-mood hypothesis (Husain et al., 2002; Nantais & Schellenberg, 1999; Schellenberg & Hallam, 2005; Schellenberg et al., 2008; Thompson et al., 2001; Thompson et al., 2011), it is suggested that a sound environment judged to be stimulating and pleasant would be the ideal environment to optimize performance (for details see Schellenberg & Weiss, 2013). It was then expected that the stimulating music condition would be the one in which the Stroop interference measure and the error rate will be the lowest. In contrast to our hypotheses, the presence of pleasant and stimulating music during the accomplishment of the task did not significantly improve task performance. A small tendency to make more errors on congruent trials in this sound environment was also noted. These results differ from those of previous work studying the effect of background music's arousal level on selective attention (Cloutier et al., 2020; Fernandez et al., 2019). However, these studies had as objective to make comparisons of groups (elderly vs young adults), while the present study had an objective of generalization to the adult populations. Furthermore, the tasks were different since they assessed selective visual attention with the Flanker task while the Stroop task, in our case, involved language processing. On the other hand, although our sample size is large, the number of sound conditions in our study may affect the statistical power of the results. It would therefore be interesting to investigate whether the results would be the same with a larger sample size in future studies.

A key finding of this study is a negative effect on attentional performance in the presence of noise-matched music stimuli (low-pleasantness). These results converge with previous work by Masataka & Perlovsky (2013) and Slevc and colleagues (2013) showing lower performance on a similar Stroop task in the presence of dissonant music (sound pairings perceived as generally unpleasant or possessing low-pleasantness valence). Interestingly in these studies, greater consonance (sound pairings perceived as generally pleasant or possessing a high-pleasantness valence) led to better performance on the Stroop task. It also is in this direction that the results of our study point, by taking into account the trend, although small, between the Stroop interference measure and the valence judgments scores for each sound condition obtained during a simple regression analysis. Indeed, according to this trend, the fact of finding a sound environment as very pleasant could have a positive effect on attentional performance. Overall, these results suggest that the valence, the pleasant or unpleasant character of a sound environment, is probably an important element to consider in the search for an optimal sound background environment in order to promote attentional performance.

In previous work, the relationship between background music and cognitive performance seems to be affected by the degree of familiarity with the musical stimulus (if the music was already known to the participant; Feng & Bidelman, 2015; Pereira et al., 2011). Higher familiarity has a positive effect on performance for cognitive tasks (Darrow et al., 2006; Speer, 2011; Giannouli, 2012). One potential limitation of our study is that, despite an attempt to select equally familiar music of similar valence, the stimulating musical stimuli were rated as more familiar to the participants than the relaxing musical stimuli (see **supplementary materials** for details). It is then surprising that the present findings did not support an effect of stimulating music on task performance given that the stimulating music condition was biased towards higher familiarity.

Taken together, our findings suggest that it is not sufficient for background music to be arousing and familiar in order to enhance attentional performance as suggested by the Arousal-mood hypothesis, and that factors related to individual musical taste or habits may be driving the effects found in previous studies. Indeed, the valence seems to be a promising variable to be explored in more detail in future studies in order to better understand the effects of it in relation to those factors.

Finally, based on the results of this study, we can therefore recommend that tasks requiring selective attention can be performed in an environment of silence as well as with pleasant instrumental music. Findings from this study can be extended to practical use in environments with loud or unpleasant intermittent noises (for example open-plan offices or when spaced for remote work from home must be shared). According to Szalma & Hancock (2011), intermittent short noise bursts are the most disturbing forms of noise; these could be the sound of a horn outside, the laughter of a colleague in a nearby open-plan office, a family member shutting a door nearby, etc. Having music in the background may be an efficient tool, equal to working in silence, for masking unpleasant intermittent noises while maintaining a similar level of selective attention on a given task. In this light, future work comparing the presence of music with pleasant noises (such as waves or waterfall noises) would be interesting to investigate given their potential for masking intermittent noises and their higher valence level in comparison with experimental-generated noises.

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Annexes

(supplementary material)

Annexe 1

Table S1

Description of musical stimuli

		Results from the emotional judgment of 46 non-musicians (Nadon et al., 2016)			Descriptive information of each stimulus	
Piece title	Composer	Arousal[a]	Valence[b]	Familiarity[c]	Tempo (bpm)[d]	Interpret
Neutral music for the practice part						
Cello Suite No. 1 in G Major (BWV 1007): 1. Prélude	Bach	51.45 (24.1)	83.88 (22.78)	87.72 (17.58)	135	István Várdai
Relaxing music						
Clarinet concerto in A major (K622) – 2. Adagio	Mozart	13.28 (12.2)	78.86 (20.62)	51.52 (31.68)	80	Anthony Pike, English Chamber Orchestra & Ralf Gothóni
Rêverie	Debussy	13.77 (11.7)	78.34 (18.81)	35.14 (34.26)	65	Rebecca Arons
Goldberg variations (BWV988) – Aria Da Capo	Bach	10.35 (10.35)	81.26 (17.88)	33.21 (34.07)	75	Nicola Frisardi
Suite bergamasque – 3. Clair de lune	Debussy	9.5 (9.65)	84 (17.51)	57.54 (41.24)	70	François-Joël Thiollier
Stimulating music						
Can-can from Orpheus in the Underworld	Offenbach	82.27 (14.52)	76.21 (22.71)	89.37 (20.7)	160	Charles Gerhardt & London philharmonic orchestra
Piano Sonata No.11 in A Major (K331) – Rondo: alla turca	Mozart	73.33 (23.86)	84.72 (15.53)	94.92 (14.71)	110	Finghin Collins

Russian dance from The Nutcracker	Tchaikovsky	88.66 (12.42)	78.01 (19.99)	86.38 (24.27)	140	Heinz Rögner & Berlin Radio Symphony Orchestra
Concerto No. 1 in E major, Op. 8 (RV 269) – Spring 1. Allegro	Vivaldi	72.45 (17.66)	74.78 (24.44)	94.74 (14.81)	115	Jonathan Carney & Royal Philharmonic Orchestra

Note. This table presents means (and standard deviations) for emotional judgment of arousal, valence and familiarity compiled with a computerized version of visual analogue scales. The table shows the data from the previous research by Nadon et al. (2016).

[a] 0 = very relaxant, 100 = very stimulating

[b] 0 = very unpleasant, 100 = very pleasant

[c] 0 = unknown, 100 = very familiar

[d] bpm = beat per minute

Annexe 2

Table S2

Participant judgment of auditory stimuli

	Results from the emotional judgment of 46 non-musicians (Nadon et al., 2016)			Results from the emotional judgment of 46 non-musicians from this study		
Stimuli title	Arousal[a]	Valence[b]	Familiarity[c]	Arousal[a]	Valence[b]	Familiarity[c]
Relaxing music and their noise-matched condition						
Clarinet concerto in A major (K622) – 2. Adagio	13.28 (12.2)	78.86 (20.62)	51.52 (31.68)	17.44 (18.12)	85.32 (12.68)	60.28 (31.32)
Noise-matched to Clarinet concerto				56.47 (21.21)	15.08 (19.33)	17.88 (29.03)
Mean comparison between music and noise-matched				-9.59***	20.64***	8.79***
Rêverie	13.77 (11.7)	78.34 (18.81)	35.14 (34.26)	12.91 (18.05)	82.96 (14.95)	33.28 (25.12)
Noise-matched to Rêverie				57.84 (21.09)	11.03 (15.34)	19.90 (28.26)
Mean comparison between music and noise-matched				22.95***	-10.67***	2.6*
Goldberg variations (BWV988) – Aria Da Capo	10.35 (10.35)	81.26 (17.88)	33.21 (34.07)	9.83 (13.17)	81.89 (15.79)	30.62 (27.42)
Noise-matched to Aria da capo				54.42 (20.36)	19.29 (22.06)	16.89 (27.16)
Mean comparison between music and noise-matched				-12.57***	17.84***	2.56*
Suite bergamasque – 3. Clair de lune	9.5 (9.65)	84 (17.51)	57.54 (41.24)	6.16 (9.16)	88.00 (15.24)	66.49 (33.36)
Noise-matched to Clair de lune				52.89 (21.61)	14.05 (18.27)	17.04 (28.54)
Mean comparison between music and noise-matched				-13.38***	20.32***	8.98***
Stimulating music and their noise-matched condition						
Can-can from Orpheus in the Underworld	82.27 (14.52)	76.21 (22.71)	89.37 (20.7)	81.67 (15.37)	77.54 (19.49)	84.01 (22.13)
Noise-matched to Can-Can				56.28 (19.36)	15.03 (16.38)	17.95 (28.85)

Mean comparison between music and noise-matched				7.9***	16.87***	14.45***
Piano Sonata No.11 in A Major (K331) – Rondo: alla turca	73.33 (23.86)	84.72 (15.53)	94.92 (14.71)	75.73 (22.01)	83.78 (20.49)	95.98 (7.67)
Noise-matched to Rondo: alla turca				60.70 (18.02)	11.95 (15.16)	17.64 (27.92)
Mean comparison between music and noise-matched				3.02**	18.0***	19.19***
Russian dance from The Nutcracker	88.66 (12.42)	78.01 (19.99)	86.38 (24.27)	84.99 (16.24)	83.47 (19.74)	89.36 (18.89)
Noise-matched to Russian dance				57.97 (18.19)	13.64 (16.59)	22.40 (31.62)
Mean comparison between music and noise-matched				8.22***	17.49***	14.65***
Concerto No. 1 in E major, Op. 8 (RV 269) – Spring 1. Allegro	72.45 (17.66)	74.78 (24.44)	94.74 (14.81)	75.28 (20.02)	82.37 (18.59)	96.05 (6.42)
Noise-matched to Spring - Allegro				57.92 (20.12)	11.64 (14.91)	16.43 (27.13)
Mean comparison between music and noise-matched				4.66***	18.23***	19.7***

Note. For the music and noise-matched rows, this table shows means (and standard deviations) for emotional judgments of arousal, valence and familiarity compiled with a computerized version of visual analogue scales. The table presents the data from previous research by Nadon et al. (2016) and the new data from this research using the same musical excerpts. For the mean comparison between music and noise-matched rows, paired-samples t-tests were performed to compare mean values for emotional judgments of valence, arousal and familiarity for all conditions and scores presented are t-scores.

[a] 0 = very relaxant, 100 = very stimulating

[b] 0 = very unpleasant, 100 = very pleasant

[c] 0 = unknown, 100 = very familiar

*p < .05.

**p < .01.

***p <.001.

Annexe 3

Table S3

Comparisons between judgments of valence, arousal, and familiarity for each sound condition

	df	*t*	*p*	Effect size (η^2)
Valence				
Relaxing music/Stimulating music	183	1.57	=0.119	=0.01
Relaxing music/Noise-matched relaxing music	183	40.25	=0.000	=0.90
Relaxing music/Noise-matched stimulating music	183	44.33	=0.000	=0.92
Stimulating music/Noise-matched relaxing music	183	31.31	=0.000	=0.84
Stimulating music/Noise-matched stimulating music	183	35.13	=0.000	=0.87
Noise-matched relaxing music/Noise-matched stimulating music	183	1.74	=0.084	=0.02
Arousal				
Relaxing music/Stimulating music	183	-36.89	=0.000	=0.88
Relaxing music/Noise-matched relaxing music	183	-22.46	=0.000	=0.73
Relaxing music/Noise-matched stimulating music	183	-24.78	=0.000	=0.77
Stimulating music/Noise-matched relaxing music	183	11.46	=0.000	=0.42
Stimulating music/Noise-matched stimulating music	183	11.12	=0.000	=0.40
Noise-matched relaxing music/Noise-matched stimulating music	183	-3.01	=0.003	=0.05
Familiarity				
Relaxing music/Stimulating music	183	-16.84	=0.000	=0.61
Relaxing music/Noise-matched relaxing music	183	10.30	=0.000	=0.37
Relaxing music/Noise-matched stimulating music	183	9.77	=0.000	=0.34
Stimulating music/Noise-matched relaxing music	183	34.01	=0.000	=0.86

Stimulating music/Noise-matched stimulating music	183	33.11	=0.000	=0.86
Noise-matched relaxing music/Noise-matched stimulating music	183	-0.75	=0.454	=0.00

Notes. This table presents the results for paired t-test analysis.

Annexe 4

Table S4

Means and standard deviations for all study variables by sound condition

Variables	Sound conditions				
	Silence	Relaxing music	Stimulating music	Noise-matched relaxing music	Noise-matched stimulating music
Congruent Stroop RT (ms)	842.67 (168.67)	839.05 (156.60)	856.64 (120.23)	843.63 (147.86)	836.15 (154.28)
Incongruent Stroop RT (ms)	1093.47 (192.56)	1075.64 (170.17)	1096.68 (168.50)	1083.66 (180.23)	1081.05 (181.72)
Stroop Interference Effect (ms)	251.02 (121.50)	236.43 (123.84)	240.11 (116.00)	239.96 (95.66)	240.11 (123.95)
ER: Congruent Stroop (%) [a]	0.74 (1.87)	0.41 (1.10)	0.54 (1.66)	0.92 (2.21)	0.93 (1.93)
ER: Incongruent Stroop (%) [b]	7.33 (7.33)	8.04 (8.47)	9.92 (8.98)	9.44 (9.20)	8.52 (8.28)
Unsuccessful rate (%) [c]	5.72 (5.62)	6.18 (6.39)	7.00 (6.11)	6.70 (5.84)	6.01 (5.55)

Note. This table shows mean (and standard deviations) values. Data in the first three rows are in milliseconds (ms) and data in the last three rows are in percentages; see information below for more details.

[a] Error rate: Congruent Stroop: failed trials for congruent trials/total number of congruent trials (failed + successful)

[b] Error rate: Incongruent Stroop: failed trials for incongruent trials/total number of incongruent trials (failed + successful)

[c] Unsuccessful rate: missed trials + failed trials (wrong answer)/total number of trials (missed + successful + failed)

Annexe 5

Table S5

Summary of significant results to analyzes of correlations between different performance measures and emotional judgments scores of valence and arousal for each sound condition

Sound condition	Performance measures	Emotional judgment	Correlation coefficient (r)	Interpretation
Stimulating music	Mean interference	Valence	-0,354 (0,05 bilateral)	Considering stimulating music as very pleasant is associated with a lower interference score in this condition.
Stimulating music	Total mean RT	Arousal	0,298 (0,05 bilateral)	Considering stimulating music as very stimulating is associated with a higher total response time in this condition.
Noise-matched stimulating music	Mean RT to congruent trials	Valence	0,307 (0,05 bilateral)	Considering the noises generated by stimulating music as very unpleasant is associated with a lower response time to congruent trials in this condition.

Note. RT = Response time